IMPROVED PERCEPTION-REACTION TIME INFORMATION FOR INTERSECTION SIGHT DISTANCE

Research, Development, and Technology

Turner-Fairbank Highway Research Center
6300 Georgetown Pike
McLean, Virginia 22101-2296

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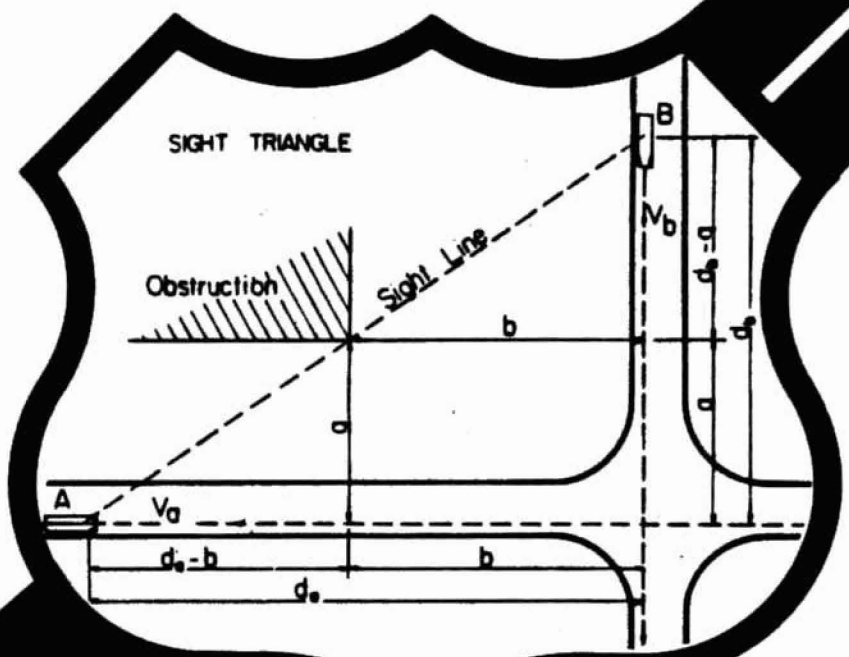

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16. Abstract

Perception-reaction time (PRT) data were obtained in an operational setting to assess the adequacy of existing PRT specifications for intersection sight distance standards. A sample of 124 subjects traversed a 3-hour driving circuit in an instrumented vehicle.

An analysis of the YIELD-controlled (Case II) reaction data showed that the first reaction occurred before stopping sight distance in over 90 percent of the trials. On the basis of this finding and the recent finding that the PRT associated with stopping sight distance was adequate, it was concluded that the current driver time-related specifications for Case II intersections are adequate.

The PRT measured for STOP-controlled (Case III) intersections was the interval from the first head movement after a stop to the application of the accelerator to enter the intersection. The mean PRT was 1.82 seconds, with the 85th percentile value being approximately 2.7 seconds. An analysis showed that the through movements produced a value lower than the overall mean and the turning movements produced a higher value. This led to the recommendation that the current value of 2.0 seconds be maintained for Case IIIA, but that the PRT for Cases IIIB and C (turning movements) be increased to 2.5 seconds. The results showed that there were no significant age or sex differences for any of the PRT measures.

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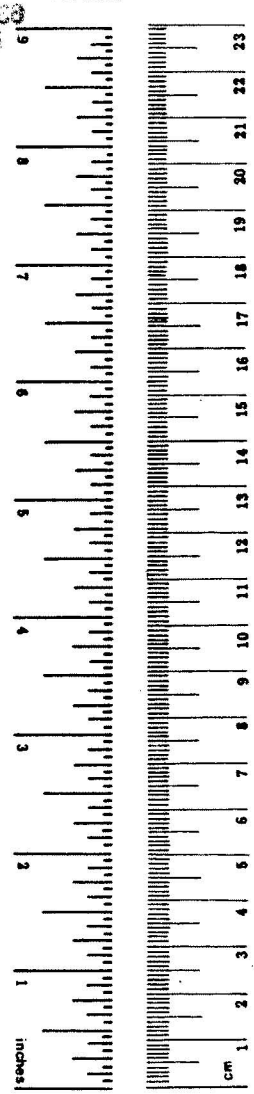
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

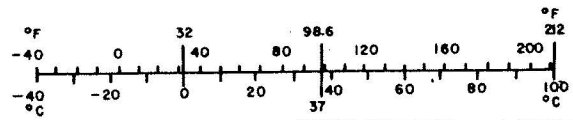
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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INTRODUCTION

A basic requirement for the safe design of a highway is that drivers have adequate sight distance for all situations. Where they do not, traffic controls and devices can be used to compensate.

Sight distances at at-grade intersections are especially important because of the potential hazard associated with conflicting vehicles. In A Policy on Geometric Design of Highways and Streets, the American Association of State Highway and Transportation Officials (AASHTO) relates intersection sight distance to six cases: ([1])

- Case I — No intersection control, with sight distance allowed for drivers to adjust speed.
- Case II — YIELD control on minor road.
- Case III A — STOP control; driver will cross intersection.
- Case III B — STOP control; driver will turn left.
- Case III C — STOP control; driver will turn right.
- Case IV — Signal control.

For each of these cases, and all sight distance standards, there is a driver perception-reaction process that is a component of the total sight distance requirement. Perception-reaction, as used in highway and traffic engineering design, is generally understood to mean the process beginning with the detection of an object (e.g., vehicle or sign) or situation (e.g., intersection) and culminating with a physical reaction by the driver. Elements of the process have been identified as detection, recognition, decision-making, and reaction.([2]) Sight distance requirements generally include a minimum perception-reaction time plus a vehicle maneuver time.

For Case I and for Cases III A, B, and C, 2.0 seconds is prescribed by AASHTO as the appropriate perception-reaction time. For the Case III situation, the AASHTO policy states that "...a somewhat lower value might apply" in urban or suburban areas. Values of 0.5 and 1.0 seconds are mentioned

without specific guidance as to which is appropriate. The perception-reaction time is not specifically mentioned for Case II, but since stopping sight distance to the intersection is the governing sight distance for this case, the 2.5-second time specified for that sight distance presumably would be appropriate for Case II. For Case IV, AASHTO states that Case III procedures apply and, therefore, the 2.0 seconds or "somewhat lower value" is the specification for perception-reaction time.([1]) Another study, Highway Design and Operations Standards Affected by Driver Characteristics, examined the basis for the various perception-reaction times. Its findings, supported by examination of historical policies and relevant literature, revealed that the 2.0 seconds used for Cases I, III, and IV was an assumed value, without supporting empirical studies.([3])

With regard to Case II, the relevant, design-related, perception-reaction value is that associated with stopping sight distance. A recent study of stopping sight distance conducted for the National Cooperative Highway Research Program included controlled field experimentation to identify the perception-reaction time for stopping sight distance.([4]) Its findings supported the currently used 2.5-second perception-reaction time specification for stopping sight distance. While this 2.5-second value is appropriate for the situation in which the driver must come to a stop due to a conflicting vehicle, it may not be for those situations in which the driver must perceive and evaluate the relative speed and location of a crossing vehicle and decide on the proper course of action. Thus it was necessary to determine the perception-reaction components associated with driver performance prior to the driver's arrival at the beginning of stopping sight distance. In essence, then, the need for this research was based on the fact that currently used values for perception-reaction time for intersection sight distance are not solidly based on empirical studies and may be inappropriate.

In recognition of the lack of empirical basis for perception-reaction times, the objectives of this study were to:

- Develop the driver-population distributions of perception-reaction time applicable to the intersection sight distance cases.
- Identify and determine the effects of variables such as age, sex, sight distance, etc., which influence driver perception-reaction time.

A key requirement of the study was that it be done in an operational setting. Hence all reported data were collected on a circuit of roads that included a variety of YIELD- and STOP-controlled intersections. The research focused on intersection sight distance for Cases II and III A, B, and C. Case I was not specifically studied because of the rare occurrence of uncontrolled intersections and the inability to locate a driving circuit which included all cases. Case IV was not specifically included because AASHTO specifies that Case III procedures apply.

METHODOLOGY

All data were collected in the field using a representative sample of subject drivers operating a vehicle instrumented to make the necessary measures of perception-reaction time.

Under the guise of a cover story which focused attention on fuel consumption as a function of driving habits and travel patterns in rural areas, subjects were instructed to drive normally and follow routing instructions that would be delivered in a timely fashion throughout the experimental session. The instructions read to each subject are shown in appendix A. Familiarity with vehicle controls and handling was established as subjects drove to the start of the circuit. An experimenter seated in the rear accompanied subjects at all times.

Each subject drove under two experimental conditions: unalerted and alerted. In the unalerted condition, subjects simply drove the circuit. Following completion of the circuit, subjects were given a brief rest during which their task in the alerted condition was described. The task was to state when an intersection was sighted, or an intersection was inferred because a vehicle on a crossing roadway was sighted. In the alerted condition, subjects drove an abbreviated version of the original circuit.

For some subjects at Case II (YIELD on minor roadway) intersections, an experimenter-controlled vehicle traveled the major roadway to create a potential conflict with the instrumented vehicle and a resulting reaction by the subject driver. The controlled crossing vehicle was used under both unalerted and alerted conditions.

The 52 intersections included in the test circuit are detailed in table 1. All were included in the unalerted condition, while only those marked with an asterisk were used in the alerted condition. The number of intersections used for the alerted condition was fewer because only at the Case II intersections was alerting expected to be influential on the measures used. Thus the alerted condition was designed to repeat all of the Case II

Table 1. Circuit and intersection characteristics.

--- INTERSECTION ---				POINT OF FIRST PERCEPTION	APPROACH SPEED	CROSS ROAD SPEED	--- SIGHT DISTANCES --- BEFORE		AFTER	
ID *	TURN	CASE	TYPE				LEFT	RIGHT	LEFT	RIGHT
1	R	-								
2	T	3	4-WAY	937	40	50	1701	1188	1701	1188
3	T	3	4-WAY	1063	45	55	636	1331	823	1450
4 *	R	3	4-WAY	792	40	50	924	2231	924	3630
5 *	R	3	4-WAY	2870	55	55	1573	806	1573	806
6	L	-								
7 *	T	2	4-WAY	2401	40	55	170	212	170	287
8 *	R	3	T	2165	35	50	410	915	817	926
9	R	-								
10	L	3	T	1055	45	55	1853	2886	1925	3276
11	R	3	T	921	55	55	2019	1861	2019	1861
12	L	3	4-WAY	2422	55	45	1743	1538	2075	1538
13	R	3	T	1815	55	55	2000	2000	2000	2000
14	R	-								
15	R	3	4-WAY	937	40	50	1701	1188	1701	1188
16	L	3	4-WAY	873	30	45	1586	3514	1586	3514
17	R	-								
18 *	R	2	4-WAY	2401	40	55	170	212	170	212
19 *	R	3	T	921	55	55	2019	1861	2019	1861
20 *	T	3	4-WAY	2422	55	45	1743	1538	2075	1538
21	R	-								
22	L	3	4-WAY	1063	45	55	636	1331	823	1450
23	R	3	T	381	40	45	500	681	1227	850
24	R	-								
25 *	T	2	4-WAY	2620	55	50	434	1547	532	1547
26 *	L	3	4-WAY	3050	35	55	779	1693	1350	1831
27	L	-								
28	T	3	4-WAY	792	40	50	924	2231	924	3630
29 *	R	3	4-WAY	3488	55	55	1152	2071	1432	2243
30	L	-								
31 *	L	2	4-WAY	1429	45	50	1328	426	1328	426
32 *	R	3	4-WAY	2820	50	50	1316	489	2081	602
33	R	-								
34	L	-								
35 *	L	2	4-WAY	641	40	55	2221	0	5008	1224
36 *	L	3	T	1263	50	55	299	2323	299	2577
37	L	-								
38 *	T	2	4-WAY	1429	45	50	1328	426	1328	426
39 *	L	2	T	1846	40	45	76	53	76	53
40	R	-								
41 *	T	2	4-WAY	641	40	55	2221	0	5008	1224
42 *	L	1	T	1034	40	55	1060	1218	1061	1193
43 *	L	1	T	1121	55	55	527	146	579	228
44	R	-								
45 *	L	2	4-WAY	2620	55	50	434	1547	532	1547
46	T	3	4-WAY	2870	55	55	1573	806	1573	806
47	R	3	4-WAY	3129	55	55	4136	3968	4912	3968
48	R	-								
49	R	3	T	2910	40	55	1083	2454	1083	2454
50	R	-								
51	T	3	4-WAY	3129	55	55	4136	3968	4912	3968
52	L	1	T	2250	50	55	783	274	907	715

*Intersections used in the alerted condition.
Note: 1 ft = 0.305 m; 1 m/h = 1.61 km/h.

intersections for which unalerted data were collected. Intersection Cases I, II, and III are noted as 1, 2, and 3. The remaining intersections simply provided continuity to the circuit as turning intersections, where subjects had the right-of-way. Subject movements at each intersection are designated in the "turn" column as left (L), right (R), and through (T).

Test intersections were further classified as T or crossroad (4-way). For each test intersection, a distance indicating the point of first perception of the intersection is also provided. The measurement represents the average distance upstream of the intersection where it first became visible when approached by a sample of highway researchers over a number of trials.

The approach and crossroad speeds represent the respective posted speed limits for the two roadways forming the intersection. Average running speeds are presented where posted speeds were not available. Also presented is sight distance available along each leg of the crossing roadway at the intersection. The Case II sight distances were observed from stopping sight distance on the approach roadway. The Case III sight distances were observed from the stop position at the STOP sign. Since the circuit was decidedly rural, the before-after categorization reflects changes in available sight distance that resulted from the harvesting of crops during the data collection period.

In all, 125 subjects were recruited and screened to ensure possession of a valid operator's license and the use of corrective lenses if required by the license. Table 2 shows the resulting distribution of age by sex.

Table 2. Subjects by age and sex.

Age	Female		Male		Total	
	N	%	N	%	N	%
16 - 24	5	(4.0)	8	(6.4)	13	(10.4)
25 - 34	3	(2.4)	5	(4.0)	8	(6.4)
35 - 44	14	(11.2)	15	(12.0)	29	(23.2)
45 - 54	14	(11.2)	11	(8.8)	25	(20.0)
55 - 64	12	(9.6)	15	(12.0)	27	(21.6)
≥ 65	7	(5.6)	16	(12.8)	23	(18.4)
Total	55	(44.0)	70	(56.0)	125	(100)

The instrumented vehicle, a 1982 midsize station wagon, was equipped with an automatic transmission, power steering, power brakes, a microcomputer, and a number of vehicle-performance sensors. The system continually monitored brake, accelerator, and steering activity along with distance travelled and time. Keyboard input on the same time and distance baseline enabled an experimenter to record discrete events such as head movements, presence of other traffic, arrival at specific reference points, etc. The keyboard entries included:

- Start Data, to initiate data collection by causing the computer to sample all sensors every second.
- Head Left; Head Right, to record each perceptible driver head movement that occurred after passing the point of first perception of an intersection.
- Vehicle Left; Vehicle Right, to record the presence of vehicles on the crossing roadway, as detected by the experimenter.
- Vehicle Ahead, to record a vehicle ahead of the experimental vehicle on the approach to an intersection.
- Comment, to record the point at which the subject announced the sighting of the intersection during the alerted condition.
- CV Delay, to indicate occasions where already recorded crossing vehicles apparently ceased to influence the subject driver because of turns, stops, etc. When the controlled crossing vehicle was in use, this key indicated delay in the controlled vehicle's arrival.
- CV Center, to indicate when each crossing vehicle had cleared the center of the intersection.
- Route Flag, to indicate instances when the subject failed to turn in the indicated direction.
- Recovery, to enable the otherwise automatic route to be dynamically redefined. The key was used primarily during the alerted condition to skip segments of the circuit, and under recorded "route flag" conditions to reestablish the correct path.
- Other, to record any event which the experimenter felt could influence the subject driver's behavior. Activation of this key was always accompanied by an explanatory log entry.
- End Data, to signal the end of sensor sampling. It was activated when the subject vehicle had cleared the intersection or when any recorded crossing vehicle cleared the intersection after the subject cleared it, whichever occurred later.

The various perception-reaction times (PRT's) were derived from the data files automatically, by differencing the times associated with two events: reaction time minus perception time.

The raw data file was created sequentially and contained the automatic and experimenter-coded data noted above. Each data point, automatic or experimenter-coded, was stored with a time hit, which consisted of a count of elapsed seconds. Automatic data were stored at 1-second intervals, and experimenter-coded data were stored when they were entered via the keyboard.

Perception-reaction times were obtained in processing by scanning the sequence of data points in the order they were stored (sequentially by time) and locating the two points of interest. For Case II intersections, start of the perception-reaction interval was the point of first possible perception and, for the alerted condition, the point at which the subject detected the intersection. Each of these points was stored as experimenter-coded data, along with a time hit. The end of the PRT interval was defined as accelerator release, or brake application, whichever came first. This could be found by examining the automatic data records and looking for a "0" accelerator value, or a positive brake value. PRT was then calculated as the difference between the time values stored with the two points.

For Case III intersections, the beginning of the PRT interval was defined as either the point at which the vehicle came to a stop, or as some particular head movement sequence, depending upon the PRT definition used. Part of the automatic data was a distance value; when this value changed by no more than 1 ft from one, 1-second time interval to the next, the vehicle was assumed to be stopped. Head movements were coded by the experimenter. The end of the PRT interval was defined as either brake release or accelerator depression.

UNCONTROLLED INTERSECTIONS--CASE I

Case I intersections were not included in the study because it was not possible within the site-selection time frame to locate a driving circuit which included enough Case I four-way intersections along with a sufficient number of Case II and III intersections. The lack of four-way Case I intersections and the absence of a through-movement possibility led to the decision to exclude Case I intersections entirely in order to include a larger number of Cases II and III and, therefore, a wider range of geometrics for these cases. Part of the underlying rationale for totally eliminating Case I was that the requirement to slow significantly to make the turn at a T-type Case I intersection available within the circuit would produce performance that would be very similar to that for a Case II intersection, where the existence of the YIELD sign dictates a reduction in speed.

YIELD CONTROL ON MINOR ROAD--CASE II

The second of the four cases of intersection sight distance described in AASHTO's A Policy of Geometric Design of Highways and Streets concerns intersections where the minor roadway is controlled by a YIELD sign. According to the Uniform Vehicle Code, the motorist must, in response to the YIELD sign, slow down and, if required for safety (i.e., if a vehicle is within or near the intersection), stop before entering the intersection.([2]) As specified by AASHTO:

> The sight distance (i.e., approach sight triangle) for the vehicle operator on the minor road must be sufficient to allow the operator to observe a vehicle on the major roadway, approaching from either the left or right, and then through perception, reaction and braking time, bring the vehicle to a stop prior to reaching the intersecting roadway. . .([1])

In figure 1, with vehicle B on the minor street, there are two sight distances of consequence. The first is the minimum stopping sight distance for the motorist in vehicle B to see the YIELD sign or the intersection and come to a complete stop if necessary. This would be distance d_b, which is measured to the center of the far-side crossing lane. This stopping sight distance is a basic requirement for all sections of a highway.

The second sight distance of consequence is the unobstructed sight line to vehicle A, which is approaching the intersection on the major street from the right of vehicle B. There is an equal sight triangle requirement to the left. According to AASHTO policy, the legs of the right triangle, d_a and d_b, are determined by the respective stopping sight distances on each road, based on the design speed.([1])

Since two legs of the sight triangle are determined by stopping sight distance, the perception-reaction time specification presumably should be the same 2.5 seconds used in determining stopping sight distance along any highway. However, an argument could be made that the perception-reaction time should be longer because two vehicles approaching the same intersection at right angles is a more complex situation.

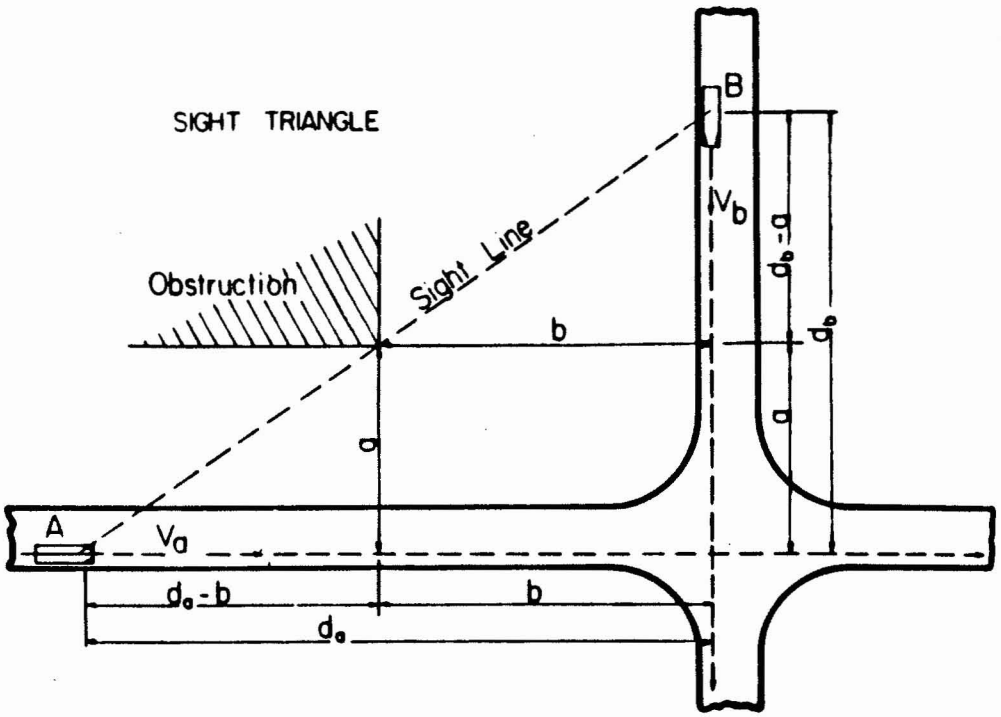

Figure 1. Case I and II no control and YIELD control on minor road (after AASHTO).

AASHTO determines stopping sight distance along any highway to a 6-in (15.2 cm) object in the roadway ahead, for which a stop may be required to avoid collision. The motorist must detect and recognize the object, decide on a course of action, and then react. For the purpose of highway design, 2.5 seconds is allowed for all these steps.(1)

A recent study by the University of Michigan's Transportation Research Institute found the 95th percentile (for the test subjects) perception-reaction time for stopping sight distance to be 1.6 seconds. They concluded that ". . . at least a 50 percent correction factor was appropriate to allow for a driving population that includes persons who are relatively fatigued, less attentive, or whose senses have been dulled by drugs of some kind."(4) Since the corrected value of 2.4 seconds was so close to the current 2.5-second specification, they recommended that the 2.5-second standard be retained.

On a YIELD-controlled approach, the perception-reaction process is more complicated. After the driver has detected and recognized the intersection and the YIELD sign, the driver must establish whether a vehicle is approaching from the side and, if so, whether it is close enough to require stopping for. If the intersection has a wide sight triangle, the driver may be able to detect approaching vehicles along the major road well in advance of stopping sight distance, or even before the intersection itself is seen. Nevertheless, the perception-reaction process should certainly be longer than if the object to be sighted were a stationary vehicle straight ahead. If the 2.5-second standard is appropriate for "straight-ahead" stopping sight distance, then the standard for a Case II, YIELD-controlled intersection should perhaps be longer.

Establishing perception-reaction time in a field situation is difficult. This can be appreciated when one understands the perception-reaction process. If for simplicity the perception-reaction and maneuver response to a YIELD-controlled intersection were assumed to be sequential, they could be depicted as shown in figure 2. Moving backwards or upstream from the intersection, one sees that the driver requires braking distance, with actual braking starting at time T_3. This is preceded by a reaction period that entails taking the foot off the accelerator and depressing the brake. Reaction starts at time T_2 and ends at time T_3. Reaction is preceded by a decision period, starting at time T_1, and ending at time T_2. If all these activities are to be performed successfully, the driver must have been able to recognize the situation (i.e., YIELD sign and presence of a vehicle on the major roadway) by time T_1. The final component to Case II perception-reaction, T_0, represents the point at which the intersection first becomes visible.

One can determine times T_4, T_3, and T_2 from the vehicle instrumentation system. For the alerted subject driver, time T_1 can also be established by the experimenter's input representing subject's stated recognition of the intersection. However, for the unalerted condition, the time between T_0 and T_1 is not known.

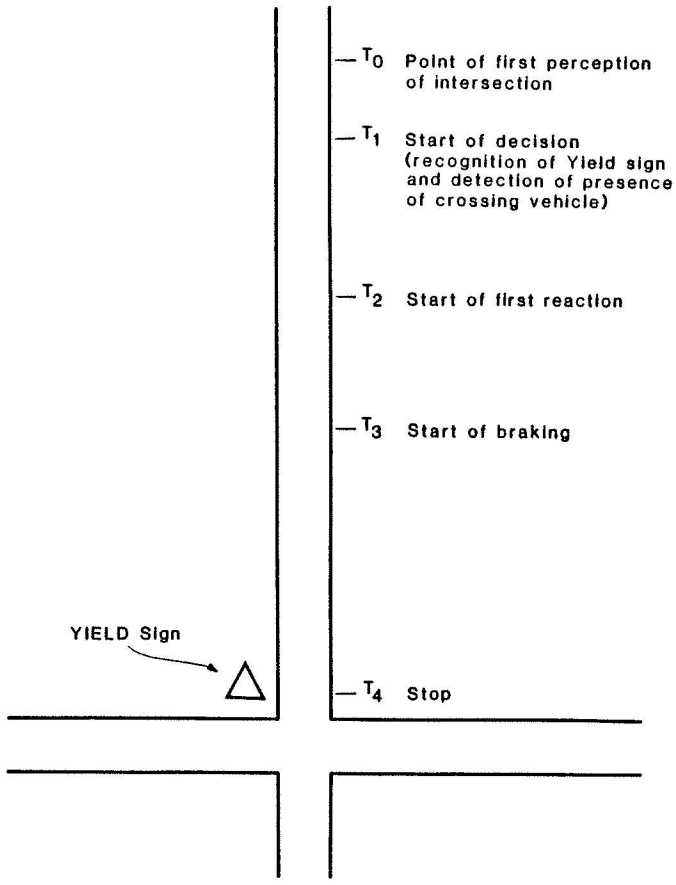

Figure 2. Perception-reaction process for Case II intersections.

Thus, it was necessary as part of the experimental protocol that a point of first possible perception of each intersection be determined before testing. The point was established by the research staff, who slowly approached each intersection and fixed the point along the approach where the intersection or controlling traffic sign was recognizable. For all intersections, the distance from this point to the intersection was much longer than stopping sight distance. Most distances were longer than 1,000 ft (305 m) and the shortest distance was about 620 ft (189 m), which is nearly twice as long as the desirable stopping sight distance for the 40 m/h (64 km/h) operating speed to that intersection. For this reason it was not necessary for drivers to react quickly after detecting the intersection. Thus the perception-reaction times as measured from point of first perception (T_0) to the point of first reaction tended to be long: on the order of 20 seconds.

1. Case II Results

The Case II field data provide several types of information related to the behavior of drivers upstream of the point at which stopping sight distance begins. First, there are data as to the mean time of the first reaction relative to the point at which the intersection or YIELD sign can be seen. Recall that subjects drove under both unalerted and alerted conditions, and that in the alerted condition provided information as to when they first perceived an intersection or YIELD sign.

Data from the unalerted condition, then, provide an empirical indication of the time drivers take to respond after the intersection becomes visible. The alerted condition, on the other hand, provides data as to an actual perception-reaction time. Since one cannot, in real-world situations, predict where drivers will see an intersection, the data from the unalerted condition are more useful for design purposes.

With regard to the first reaction, the critical factor is not the absolute time the driver takes to react after the intersection becomes visible, but whether the first reaction takes place before the driver reaches stopping sight distance: the point by which the safety-related decision as to the need to stop must be made. It is reasonable to assume that the first reaction, in this case the release of the accelerator or application of the brake, indicates that the driver is aware of the intersection and is in the process of monitoring the crossing roadway to determine whether a stop is necessary.

2. Case II Alerting Effects

Alerted trials were conducted at intersections that had previously been encountered on an unalerted trial. With regard to the effects of alerting, two results can be noted: the mean difference between the time when an intersection becomes visible (point of first perception) and when test subjects report seeing the intersection; and the influence of alerting on the time of the first reaction to the intersection. The mean difference between

the time an intersection became visually available and detection was reported was 7.8 seconds for four-way intersections.

It should be noted that because of the possible (and likely) lag between actual detection of an intersection and the verbal response, and an additional (shorter) lag between the subject's verbal response and its entry at the keyboard, the times recorded are slightly longer than actual perception time. As it turned out, however, the times are of no real consequence in terms of driver performance, in that the alerted and unalerted conditions did not produce any substantive differences in the perception-reaction interval. The interval for the unalerted condition was 22.1 seconds (N=600) as compared to 21.1 seconds (N=464) for the alerted condition. Most intersections were detected after the point of first perception, yet this slight lag did not result in later initial reactions on the part of the drivers.

3. Case II Approach Sight Distance Effects

The fact that alerting did not have a significant influence on the initial reaction is understandable when one considers that, for intersections with a reasonably long approach sight distance, there is no compelling need to make an adjustment immediately upon detection of the intersection. Drivers tend to tailor the response timing to the approach sight distance, as shown in table 3, where the perception-reaction interval is presented for each approach sight distance (from point of first perception [POFP] to intersection). Because the Case I intersections on the circuit exhibited characteristics which were desirable for purposes of demonstrating the approach sight distance effects, the Case I intersections are included in table 3. As shown, increases in approach sight distance produce increases in the perception-reaction interval, at least through the 1,846-ft (563 m) approach sight distance.

Table 3. Perception-reaction interval as a function of approach sight distance.

Section No.	Intersection Type	POFP to Intersection	PRT (s)
35/41	4-Way	641	5.13
42	T	1034	11.26
43	T	1121	16.38
31/38	4-Way	1429	21.48
39	T	1846	33.66
52	T	2250	25.32
7/18	4-Way	2401	34.69
25/45	4-Way	2620	30.37

Note: 1 ft = .305 m.

The reversals in interval length for the longer approach sight distances lie outside the critical limits for design recommendations and need not be explained.

4. Case II Age and Sex Effects

No significant sex differences were observed in comparing the interval between visibility of the intersection and the first response. The mean response interval for males was 21.75 seconds, compared to 21.49 seconds on the average for females; these data are based on sample sizes of 635 and 429 trials respectively. Because there was only one Case II T-intersection, the data reported here are for four-way intersections only.

Similarly, age did not have a substantial effect on the perception-reaction interval. Table 4 shows for each age group the values obtained (along with the sample size) in alerted, unalerted, and combined conditions. Table 5, showing the same data with younger and older age groups collapsed, indicates that there is no practical difference between the groups.

Table 4. Case II perception-reaction intervals (seconds) by age group for four-way intersections.

	CONDITION		
AGE GROUP	UNALERT	ALERT	COMBINED
16-24	20.76 (86)	18.90 (68)	19.93 (154)
25-34	23.45 (53)	21.77 (43)	22.69 (96)
35-44	23.04 (211)	21.94 (157)	22.57 (368)
45-54	22.89 (166)	20.33 (118)	21.75 (284)
55-64	23.63 (195)	21.98 (155)	22.90 (350)
> 64	24.08 (154)	22.09 (131)	23.17 (285)

Table 5. Case II perception-reaction intervals (seconds) for younger versus older drivers for four-way intersections.

	CONDITION		
AGE GROUP	UNALERT	ALERT	COMBINED
Younger 16-44	22.54 (350)	21.14 (268)	21.93 (618)
Older > 45	23.53 (515)	21.53 (404)	22.65 (919)

5. Case II Perception-Reaction Time and Stopping Sight Distance

One critical safety-related factor associated with the initial response of the driver is whether the response occurs before the point at which stopping sight distance (SSD) begins. A response before reaching this point indicates that the driver is probably aware that a speed adjustment may be required. Given this presumed awareness, the driver can safely stop in the event that a crossing vehicle makes it necessary. Table 6 shows the percentage of drivers that exhibited the first reaction (accelerator release or brake application) before SSD. The percentages shown are for alerted and unalerted conditions, with and without crossing vehicles, along with the combined conditions. The majority of the crossing vehicle trials were those for which the crossing vehicle was controlled to meet the subject vehicle at the intersection, i.e., to create a potential conflict requiring the subject vehicle to stop.

Table 6. Percentage of drivers exhibiting first reaction before reaching stopping sight distance.

	UNALERTED				ALERTED				COMBINED			
	REACT. BEFORE SSD		REACT. AFTER SSD		REACT. BEFORE SSD		REACT. AFTER SSD		REACT. BEFORE SSD		REACT. AFTER SSD	
	N	%	N	%	N	%	N	%	N	%	N	%
No Crossing Vehicle	806	92	71	8	583	86	95	14	1389	89	166	11
Crossing Vehicle	328	89	41	11	309	81	73	19	637	85	114	15
Combined	1134	91	112	9	892	84	168	16	2026	88	280	12

One can see that, overall, drivers exhibited the first reaction upstream of SSD on 88 percent of the trials. With regard to the influence of alerting on the response, a slightly higher percentage (91 percent)) reacted before SSD on unalerted trials than on alerted (84 percent), a finding which

is maintained when crossing-vehicle conditions are taken into account (i.e., higher percentages for unalerted trials still obtain). The highest percentage of reactions before SSD (92 percent) occurs for unalerted trials with no crossing vehicles present while the lowest percentage (81 percent) occurs for alerted trials with crossing vehicles. It appears that the alerted condition of the driver combined with the observation of a crossing vehicle constitutes the highest level of certainty (the greatest amount of information) and conversely, that the unalerted condition and no observed crossing vehicle constitutes the highest level of uncertainty. Thus, where there is a higher level of uncertainty, the driver behaves more cautiously and reacts earlier, i.e., modifies speed via accelerator release or brake application, to provide a longer time frame in which to observe and decide whether a stop or significant speed reduction is necessary. When a crossing vehicle is observed under an alerted condition, the driver can decide with more confidence what is required and does not need additional decision time. The initial response is therefore made later and is related primarily to the dynamic requirements for stopping or adjusting speed. This is to some extent confirmed by the effect of controlled crossing vehicles on the initial reaction for alerted trials.

6. Case II Controlled Crossing Vehicle Effects

Controlled crossing vehicle trials were designed to produce a potential intersection conflict between the crossing vehicle and the subject vehicle. Thus, the subject vehicle was virtually always required to stop. Table 7 shows the PRT's for alerted and unalerted trials under controlled-crossing-vehicle conditions versus no-crossing-vehicle conditions. Shorter PRT's, i.e., the earlier first reactions, occurred under conditions with no crossing vehicle; further, the shortest PRT occurred for the unalerted condition. Thus, it appears that drivers do indeed react more cautiously under more uncertain conditions.

Table 7. Effects of controlled crossing vehicles on perception-reaction time (first reaction).

	UNALERTED		ALERTED		COMBINED	
	N	PRT (s)	N	PRT (s)	N	PRT (s)
No Cross. Vehicle	50	16.7	48	20.3	98	18.4
Crossing Vehicle	236	25.1	221	24.9	457	25.0

7. Case II Effects of Intersection Sight Distance Triangle

Another factor that can influence driver reaction is the sight distance triangle (SDT). The shorter the SDT on either leg of the crossing roadway, the less time the approaching driver has to look for crossing vehicles and assess their speed, and the more uncertain the driver will be as to whether a speed adjustment or stop will be necessary. The driver's decision behavior is also influenced by an intended turn at the intersection. For example, if the driver desires to make a right turn and the right leg of the crossing roadway has short sight distance while the left leg is relatively long, there may be little SDT influence evident, because the driver will not be using the lane used by a driver approaching from the right. The PRT associated with a left turn at the same intersection, on the other hand, will be greatly influenced, because the driver will not only enter the far lane, but must establish stream speed to avoid a potential rear-end conflict.

To assess the effects of SDT and also account for the potential differential influence of turn direction, each Case II intersection was characterized as having safe or unsafe legs relative to left and right turns, and, for four-way intersections, through movements. The classification scheme was based on the existing AASHTO guidelines for establishing safe SDT's.([1]) When the sight distance along the crossing roadway leg opposite the direction of a turn was shorter than that required, the data were classified as unsafe. Trials involving through movements were classified as unsafe if either leg was shorter than required.

Table 8 shows the PRT's observed for safe and unsafe trials under unalerted, alerted, and combined conditions. This analysis was designed to assess the influence of SDT safety on PRT's, and since the existence of crossing vehicles has been shown to influence PRT, the results shown in the table are based only on trials for which no crossing vehicles were present. Thus, any PRT differentials are produced primarily by SDT. It should be noted that the data shown in table 8 are for four-way intersections only.

Table 8. Effects of safe versus unsafe sight distance triangle on perception-reaction time in seconds (four-way intersections).

	SAFE		UNSAFE	
Subject Condition	N	PRT (s)	N	PRT (s)
Unalerted	167	25.7	433	20.7
Alerted	112	26.4	352	19.4
Combined	279	26.0	785	20.1

As revealed in table 8, the existence of an unsafe (short sight distance) leg on a four-way intersection does produce a slightly shorter mean PRT, i.e., the drivers, on the average, exhibit the first reaction earlier. This is further evidence that in the face of greater uncertainty drivers react more prudently.

STOP CONTROLLED INTERSECTIONS--CASE III

The AASHTO policy addresses sight distance requirements for three subcases when the minor street is controlled by STOP sign. Case IIIA applies when a driver will make a crossing maneuver; Case IIIB, when a driver will make a left turn; and Case IIIC, when a driver will turn right.

For Case IIIA (crossing maneuver), AASHTO specifies that the driver on the minor road must have sight distance from the stopped position sufficient to travel across the intersecting roadway, even if a vehicle comes into view as the driver begins the departure movements. AASHTO formulation for determining the sight distance is $SD = 1.47\ V\ (J + t_a)$, where:

- SD = sight distance along the major highway from the intersection, ft.
- V = design speed on the major highway, mi/h.
- 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, D_m, to clear the major highway pavement, s.
- D_m = distance that the stopped vehicle must travel to clear the major highway, ft, which equals $D_p + W + L_v$.
- D_p = distance from near edge of pavement to front of stopped vehicle, ft (D_p is usually assumed to be 10 ft [3.05 m]).
- W = pavement width along intended path of stopped vehicle, ft.
- L_v = length of vehicle, ft.([1])

Cases IIIB and C entail similar formulations but account for the turning maneuver as shown graphically in figures 3 and 4.

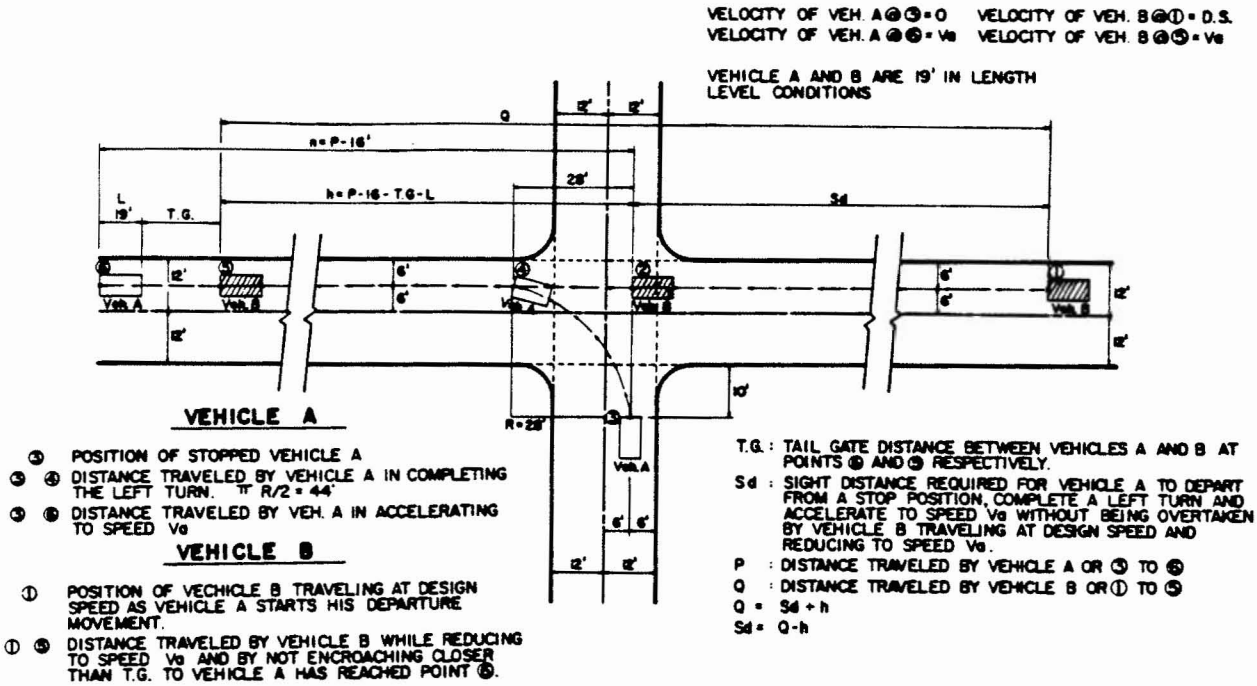

Figure 3. Case IIIB schematic, where stopped vehicle turns left onto two-lane major highway (after AASHTO).

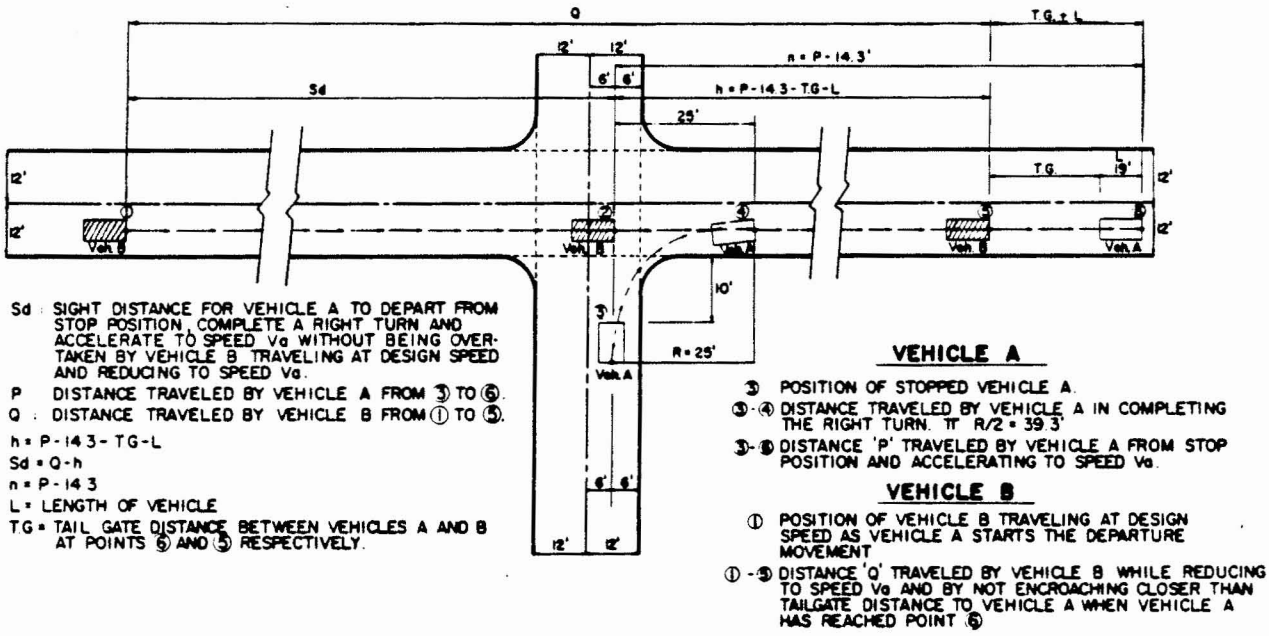

Figure 4. Case IIIC schematic, where stopped vehicle turns right onto two-lane major highway (after AASHTO).

Concerning the perception-reaction time (J), AASHTO states:

> The term J represents the time necessary for the vehicle's operator to look in both directions of 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 time from the driver's first look for possible oncoming traffic to the instant the car begins to move. Some of these operations are done simultaneously by many drivers, and some operations, such as shifting of gears, may be done before looking up or down the road. Even though most drivers may require only a fraction of a second, a large value of J should be used in design to represent the time taken by small percentage of slower drivers. A value of 2.0 is assumed. In urban or suburban areas where drivers generally use many intersections with stop sign control, a somewhat lower value might apply. Reducing J to 0.5 or 1.0 sec reduces the calculated sight distance only about 15 percent.([1])

While this material on perception-reaction time is given only for Case IIIA, it is assumed that the same value was used in the formulation of Cases IIIB and C. During the perception-reaction process, then, the motorist scans both directions for oncoming vehicles; establishes whether oncoming vehicles are present and whether the time and distance gap is sufficient to permit crossing safely; and reacts by initiating acceleration. As stated above, the start point of the perception-reaction interval is the driver's first look for possible oncoming traffic, and the end of the interval is the application of the accelerator.

A wide range of monitoring strategies are employed by drivers, strategies selected in part to satisfy preferred driving style and in part dictated by the available sight distance triangle. For a large percentage of trials at intersections with reasonable sight distance triangles, drivers completed monitoring of the crossing roadway before coming to a stop. Because of this, several different definitions of the perception-reaction interval are reported. The longest interval reported begins with the stop of the vehicle; it is referred to in subsequent discussions as perception-reaction time 1 (PRT-1). The shortest interval reported begins with the last head movement opposite the direction of the turn (for turning trials)

or the last head movement in the direction of the shortest sight-distance leg (for through-movement trials), with the head movement counts beginning after the vehicle has stopped. This definition, referred to as PRT-3, was used because it represents the termination of monitoring activity (i.e., acquisition of information as to crossing vehicles) and is therefore the best representation of decision time. The midrange interval is that stated in AASHTO, in which the interval begins with the first head movement following the stop.([1]) This is referred to as PRT-2. In all cases, the end of the interval is the application of the accelerator to enter the intersection.

1. Case III Results

Results are presented for each of the three PRT definitions described above for both four-way and T-intersections. In all cases the mean PRT value, X, is shown along with N, the number of trials on which the PRT value is based. Unequal N's across definitions largely reflect a difference in monitoring styles, i.e., the location and number of head movements. For example, PRT-1, being based on a stop (independent of head movements), always represents the largest number of trials; whereas PRT-3, involving multiple head movements, is based on the fewest number of trials because many subject drivers engaged in monitoring before the stop and did not exhibit multiple head movements after the stop.

2. Case III Sex and Age Comparisons

No practical differences, among all of the definitions of PRT, were found between male and female for either intersection type. Table 9 shows the mean values and standard deviations (SD) obtained and number of trials for each definition and intersection type.

Neither were there any practical differences observed among age groups. Table 10 shows the PRT values obtained for each definition of PRT and for each intersection type. Table 11 presents the same data with older and younger age groups collapsed. Note that the values in tables 9, 10, and 11

are based on unalerted trials where there was no crossing vehicle coded during the trial. This is a data set which provides the "cleanest" PRT data for use in establishing design guidelines, inasmuch as it is only intersection sight distance which influences the PRT values obtained. It should be noted that the inclusion of alerted trials in any of the data sets presented above produces a slight but insignificant reduction of the PRT values.

Table 9. Case III perception-reaction time by sex (in seconds).

Sex		PRT-1		PRT-2		PRT-3	
		4-way	T	4-Way	T	4-Way	T
Male	N	959	457	444	198	290	147
	$\overline{X}$	2.41	3.01	1.76	2.08	1.66	1.87
	SD	5.57	6.11	1.63	1.75	1.46	1.56
Female	N	753	328	321	148	209	111
	$\overline{X}$	2.05	2.44	1.79	1.69	1.61	1.55
	SD	4.71	4.88	1.63	1.24	1.42	1.10

3. Case III Overall PRT Distributions

The mean PRT values obtained for each type of intersection and for intersection types combined, according to each of the three definitions, are shown in table 12. Note that the PRT definition recognized by AASHTO (PRT-2) yields mean values for both types of intersections, as well as for intersection types combined, below the 2.0-second PRT value currently in use. Only the PRT-1 definition, in which timing of the PRT interval begins with a vehicle stop, yields values over the 2.0-second mean value. It is notable that regardless of PRT definition, the mean values for four-way intersections are shorter than for T-intersections.

Table 10. Case III perception-reaction time by age groups (in seconds).

Age Group		PRT-1		PRT-2		PRT-3	
		4-way	T	4-Way	T	4-Way	T
16-24	N	158	82	77	36	40	31
	$\overline{X}$	2.17	3.62	2.07	2.22	1.94	1.66
	SD	3.20	6.06	1.87	1.98	1.69	1.45
25-34	N	98	43	48	18	27	15
	$\overline{X}$	2.29	3.19	1.93	2.31	1.76	2.40
	SD	3.94	8.24	1.66	2.07	1.66	2.16
35-44	N	412	185	204	86	98	61
	$\overline{X}$	1.96	2.66	1.59	1.85	1.42	1.84
	SD	4.51	4.92	1.46	1.44	1.31	1.31
45-54	N	327	152	159	86	98	61
	$\overline{X}$	2.24	2.03	1.96	1.85	1.42	1.84
	SD	5.46	3.55	1.91	1.44	1.31	1.31
55-64	N	356	169	158	79	66	57
	$\overline{X}$	1.81	1.63	1.59	1.65	1.52	1.58
	SD	3.53	2.51	1.51	1.21	1.21	1.21
> 64	N	303	147	173	65	78	40
	$\overline{X}$	2.04	3.02	1.48	1.95	1.70	1.60
	SD	3.35	6.64	1.40	1.72	1.39	1.31

Table 11. Case III perception-reaction time in seconds for younger versus older drivers.

Age Group		PRT-1		PRT-2		PRT-3	
		4-way	T	4-Way	T	4-Way	T
Younger (16-44)	N	668	310	329	140	165	107
	$\overline{X}$	2.06	2.99	1.75	2.00	1.60	1.86
	SD	4.15	5.78	1.60	1.68	1.48	1.49
Older (> 45)	N	986	468	465	212	217	149
	$\overline{X}$	2.02	2.19	1.76	1.82	1.71	1.61
	SD	4.22	4.52	1.63	1.45	1.49	1.29

Table 12. Case III perception-reaction time--overall in seconds.

		INTERSECTION TYPE		
PRT Measure		4-way	T	Combined
PRT-1	N	1320	589	1909
	$\overline{X}$	2.21	2.84	2.40
	SD	4.43	5.29	4.72
PRT-2	N	627	279	906
	$\overline{X}$	1.77	1.94	1.82
	SD	1.65	1.62	1.64
PRT-3	N	411	209	620
	$\overline{X}$	1.60	1.76	1.65
	SD	1.44	1.43	1.44

The distributions of perception-reaction times for the three definitions of PRT for both four-way and T-intersections are shown in figures 5 through 10. The values associated with each of the figures are presented in appendix B (tables 15 through 20).

Figure 5 shows the obtained distribution for the AASHTO PRT definition, i.e., in which the PRT interval begins with the first head movement following the stop, for four-way intersections. Statistics of primary interest include the mean PRT of 1.77 seconds as well as the 85th percentile value of 2.63 seconds. It is of significance that in addition to the 765 trials on which the PRT mean values are based, there were an additional 945 trials (including the alerted trials) for which the test subjects did not exhibit any head movements following the stop. In other words, for 55.3 percent of the total (N=1710) trials, the subjects had completed monitoring (perception) before they came to a stop. Adding to this the 178 trials assigned a 0.5-second value (where the head movement occurred in the same half-second interval as the application of the accelerator), we see that 65.7 percent of the trials involved very little or no post-stop monitoring.

For the T-intersections, where the mean PRT was 1.94 seconds, the 85th percentile value was 2.81 seconds as shown in figure 6. For T-intersections, the percentage of trials on which no head movements occurred after the stop was only slightly higher (55.7 percent) than it was for the four-way intersections. The mean PRT value for T and four-way intersections combined was 1.82 seconds, with an 85th percentile value of 2.7 seconds. The distributions for the other definitions of PRT are shown on figures 7 through 10.

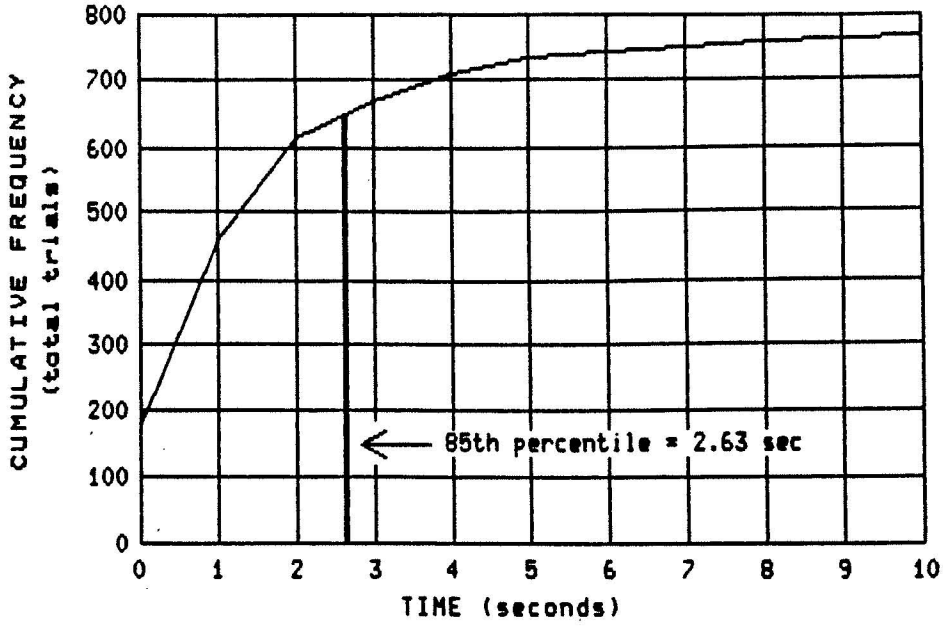

Figure 5. PRT distribution--Case III four-way (PRT-2).

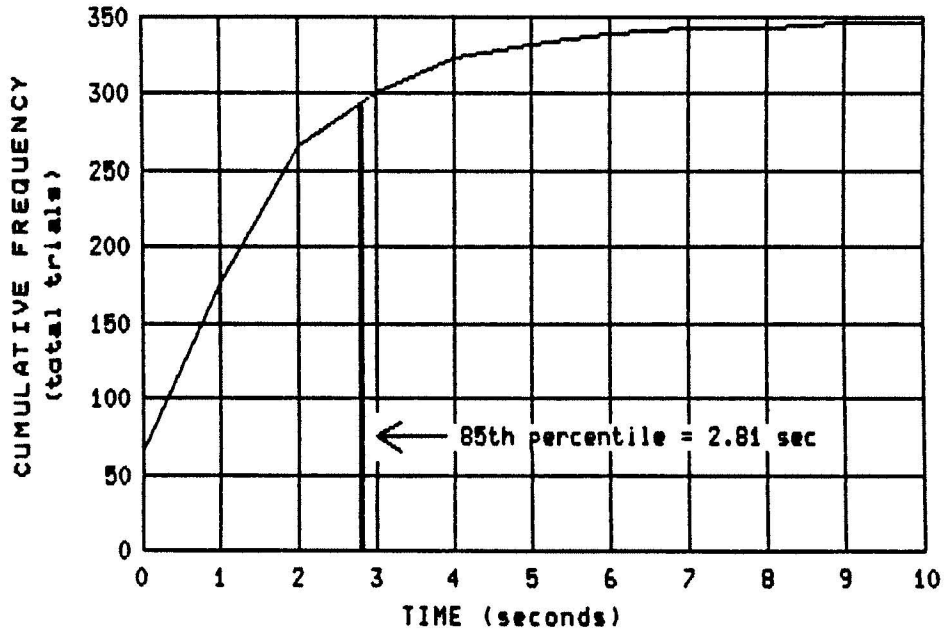

Figure 6. PRT distribution--Case III T (PRT-2).

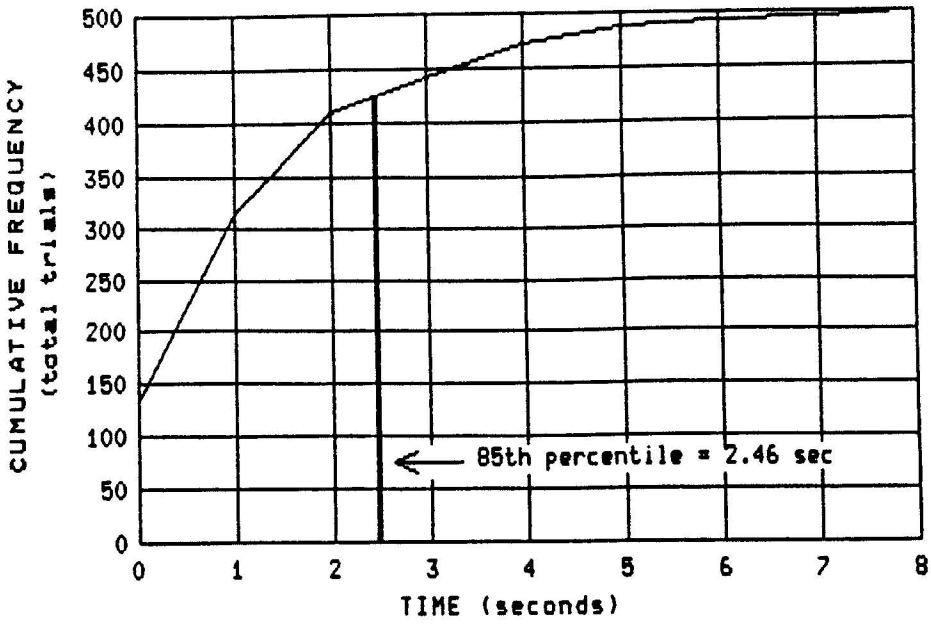

Figure 7. PRT distribution--Case III four-way (PRT-3).

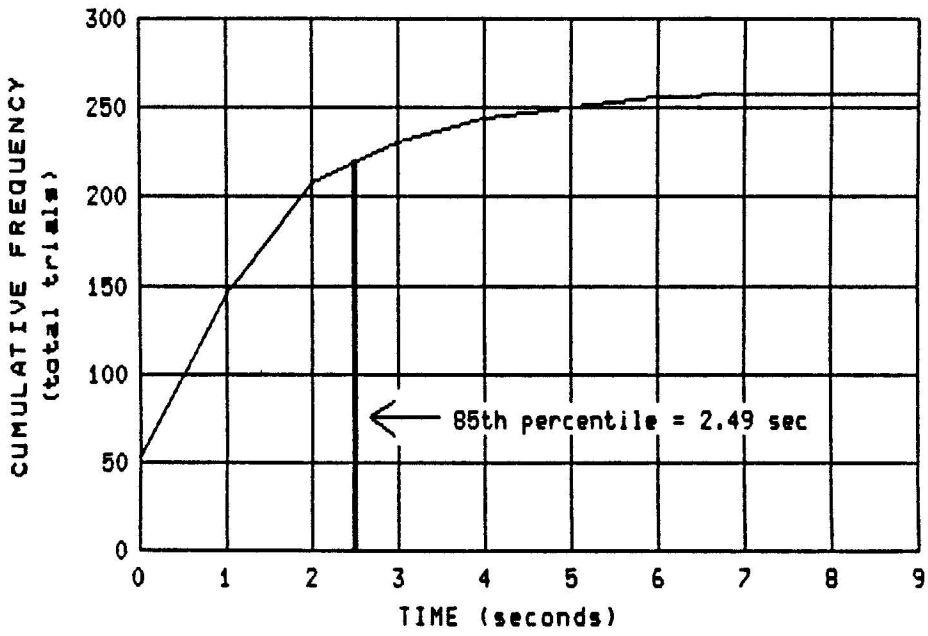

Figure 8. PRT distribution--Case III T (PRT-3).

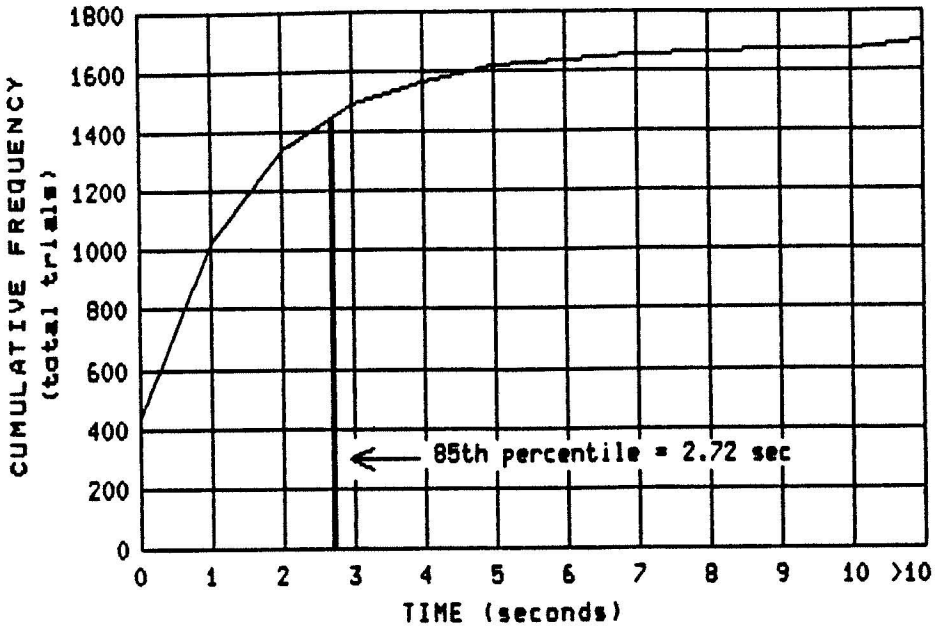

Figure 9. PRT distribution--Case III four-way (PRT-1).

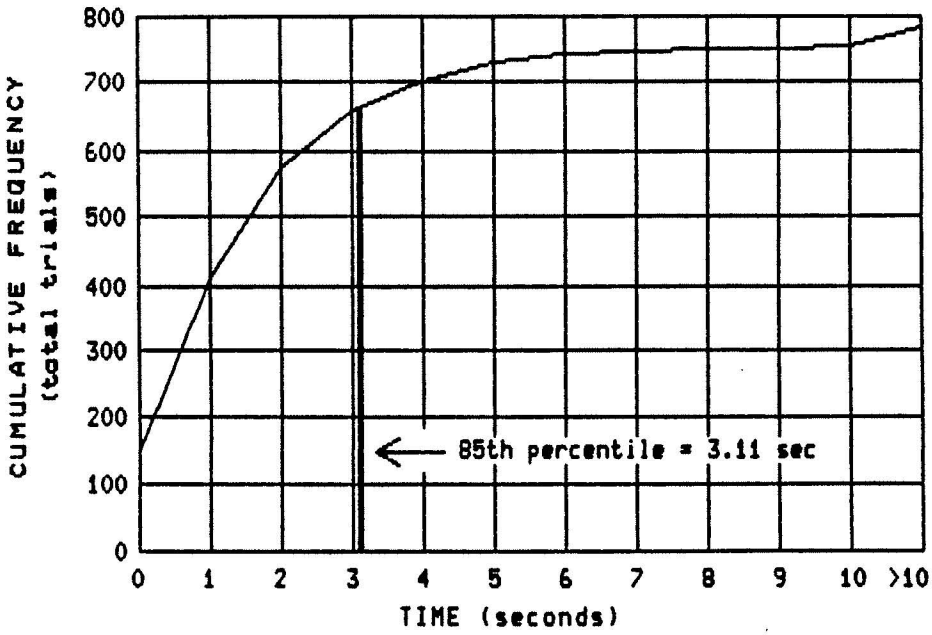

Figure 10. PRT distribution--Case III T (PRT-1).

4. Case III Effects of Other Variables

By design there were several four-way intersections on the circuit which the subject driver encountered twice. Where possible, repeat trials at the same intersection were designed such that the driver was required to make a through movement on one and a turning movement on the other. Table 13 shows the mean PRT values for turning versus through trials for the same intersections. The first column refers to the intersection numbers identified in table 1. PRT's for a through movement were, as expected, always shorter than PRT's for a turning movement.

Table 13. Comparison of Case III mean PRT's in seconds for through versus turing movements on four-way intersections.

Section ID	Through (s)	Turn (s)
2/15	1.22	2.02
3/22	1.30	1.34
4/28	1.18	2.27
5/46	1.28	2.00
12/20	1.81	2.52
47/51	1.11	2.52

Another factor which one might assume would influence PRT is sight distance. However, examination of PRT's obtained at the various sight distances indicated that this factor was not a significant determinant of PRT. It should be pointed out that the circuit contained relatively few intersections with very short sight distances.

A rare analytical opportunity was presented at five Case III intersections on the circuit at which sight distance was increased during the conduct of the study. These were intersections at which crops that created a sight distance restriction at the beginning of the data collection were subsequently harvested, causing an increase in sight distance. The Case III PRT's for subjects run before as opposed to those run after the sight distance changes are shown on table 14. Subject differences notwithstanding,

this is perhaps the best indicator of the variable effects of sight distance on PRT. The intersections in question are listed in ascending order from the one with the shortest sight distance leg (whether left or right) to the one with the longest. Note that intersection pairs 3 and 22 and 12 and 20 represent different turning movements at the same intersection. The results indicate that intersections 3, 22, 29, and 20 showed a slight decrease in mean PRT with increases in sight distance, while sections 32, 26, and 12 showed a slight increase. However, considering that the largest change represents only a 0.58-second decrease for intersection 3, none of the changes is of practical importance.

Table 14. Comparison of Case III PRT's in seconds for intersections at which sight distance changed.

Section ID	Turn Direction	Sight Distance (ft)				PRT (s)	
		Before		After			
		Left	Right	Left	Right	Before	After
32	Right	1316	489	2081	602	2.27	2.61
3	Through	636	1331	823	1450	1.60	1.02
22	Left	636	1331	823	1450	1.50	1.00
26	Left	779	1693	1350	1831	1.85	1.92
29	Right	1152	2071	1432	2243	1.83	1.50
12	Left	1743	1538	2075	1538	2.33	2.64
20	Through	1743	1538	2075	1538	1.89	1.74

Note: 1 ft = 0.305 m.

CONCLUSIONS AND RECOMMENDATIONS

This research obtained, in a fully operational setting, perception-reaction time (PRT) data to assess the adequacy of the existing PRT specifications used for intersection sight distance. The study design and selection of the subject driver sample also provided more general data on the influence of variables such as age and sex on PRT, and the influence of alerting on intersection driving behavior. A summary of the major findings is as follows:

- PRT did not vary significantly with age or sex.
- For Case II (YIELD-controlled) intersections, the initial preparatory response occurred at a point prior to stopping sight distance in nearly 90 percent of the trials. This led to the conclusion that the existing PRT design values for Case II intersections are adequate and should be retained.
- For Case III (STOP-controlled) intersections the overall mean PRT using the AASHTO definition was 1.82 seconds and the 85th percentile time was found to be approximately 2.7 seconds. For four-way intersections, the mean was 1.77 seconds, with an 85th percentile value of 2.63 seconds. For T intersections, the mean was 1.94 seconds, with an 85th percentile value of 2.81 seconds. A slightly longer time was observed for turning movements than for through movements. This led to the recommendation that the current specification of 2.0 seconds be retained for Case IIIA, but that the value for Case IIIB and C be increased to 2.5 seconds.

The sections below discuss the more general results first, with the more specific overall PRT data for Cases II and III following.

1. General

Neither age nor sex was found to have any practical influence on the PRT's measured. On the basis of the literature on the elderly driver, longer PRT's were expected for the group of drivers aged 65 and over. However, the data did not support this expectation. There was no evidence to support the contention that elderly drivers require increased sight distance to compensate for degraded, driving-related skills. This finding, however, should not be generalized to other driving situations. The detection and recognition of an intersection or a crossing vehicle, the primary visual task for this study, does not require the critical visual skills which are known to be degraded in the elderly.

The alerted trials for Case II provided the data to determine the interval between the time the intersection became visible and its detection by subject drivers. The mean time for this interval was 7.87 seconds for four-way intersections. However, because of the likely delay in detection reporting by the subject and the additional (smaller) delay in coding of the detection response by the experimenter, the true values are most likely slightly lower. The important fact is that the alerting of the drivers produced no practical change in the location of the initial driver response.

The intersection characteristics of potential importance with regard to PRT and intersection driving behavior are sight distance along the crossing roadway and, particularly for Case II intersections, the approach sight distance. While the research provided some suggestions that both of these factors might be influential, the range of sight distance characteristics on the driving circuit was not represented in enough incremental differences to make an adequate assessment of the extent of the influence.

2. Case II

The most relevant PRT measure related to the intersection sight triangle is that associated with stopping sight distance; a measure which has been shown, in a recent research study by Olson, to be adequate as currently specified.([4]) The Case II PRT's in the current study represent the interval from the time at which an intersection first becomes visible to the time at which the first reaction occurs. The observed times, in excess of 20 seconds on the average, merely reflect that the subjects had long sight distances to the intersections and did not respond until they felt it was necessary. The relevance of the initial response (the release of the accelerator or the application of the brake) is that it is a preparatory response and an indication that the driver is aware that an adjustment, in the form of a deceleration or stop, may be necessary. To the extent that this preparatory response is made before the driver reaches the point which begins stopping sight distance, there is adequate time to stop, if required, to accommodate a crossing vehicle.

In nearly 90 percent of cases, this preparatory response occurred before stopping sight distance was reached. The results do not allow for rejection of the current specification of 2.5 seconds for computing stopping sight distance. Also, the results do not provide quantitative support for the contention that Case II requires a PRT in excess of 2.5 seconds because of decision complexity. The existing PRT design values for Case II intersections are judged to be adequate.

3. Case III

The PRT associated with STOP-controlled (Case III) intersections in current AASHTO guidelines is the interval from the first head movement following the stop to the application of the accelerator for the intersection entry maneuver. On slightly over 55 percent of the trials, the subject drivers did not provide a PRT value accommodated by the above definition. That is, the monitoring of the crossing roadway was completed before the stop and no discernible head movement was exhibited after the stop. This sort of behavior is, at least in part, related to the fact that the test circuit was in a rural environment and included a number of low-volume crossing roadways. To provide a conservative PRT value, the 0-value trials were excluded from the calculations. It was felt that at higher-volume major streets, for example, a greater percentage of drivers would exhibit some post-stop monitoring behavior and that the use of only the trials where such behavior was exhibited would provide the most realistic representation of Case III PRT.

For the PRT definition most closely identified with the AASHTO description, i.e., the PRT interval beginning with the first head movement following the stop, the mean PRT is 1.82 seconds and the 85th percentile is approximately 2.7 seconds. However, when these values are divided into situations where the driver continued through the intersections versus made a turning movement, the PRT values are slightly lower for the through movement than for the turning movement, with all but one of the differences being between 0.7 and 1.4 seconds. There also appears to be an "available sight distance" influence which, due to insufficient sample size, is not

conclusively established. The finding regarding through versus turning movements suggests that consideration be given to specifying two perception-reaction times for Case III. One would be for Case IIIA, with the current value of 2.0 seconds being an adequate and reasonably conservative value. The other would apply to Case IIIB and IIIC, with a value of 2.5 seconds being more appropriate.

The additional distances that would be required for these two cases to accommodate 0.5 seconds more perception-reaction time would be a function of speed. The distances would range from 18.4 to 47.8 ft (5.6 to 14.6 m) for speeds of 25 to 65 m/h (40.3 to 104.7 km/h), respectively. These increases are only 6 and 3 percent over the current AASHTO distance standards.([1]) The current lengths for Cases IIIB and C or the new lengths that would result from an additional 0.5 seconds are both considerably longer than stopping sight distance.

Regarding the practicality of the sight distances it will be noted that the research was limited to the perception-reaction component and did not evaluate all of the components that comprise intersection sight distance. Therefore, we have no empirical basis to make a recommendation on the practicality of these distances. It is noted that above the 45-m/h (72.5 km/h) design, the required sight distances for Cases IIIB and IIIC become very long. This has more to do with assumptions about acceleration of the turning vehicle and the overtaking characteristics of the main-street vehicle than it does with the perception-reaction component. These standard distances should be judged against typical, critical-gap-acceptance data to determine their practicality.

APPENDIX A: Subject Instructions

The study in which you are about to participate is being conducted for the Federal Highway Administration, U. S. Department of Transportation. It is designed to tell us something about the effects of different driving habits, driving patterns, etc., during route following on the efficiency of fuel consumption on rural two-lane roadways.

The manner in which starting and stopping, steering, and accelerating and decelerating take place determines the fuel use efficiency for any given vehicle.

This vehicle is instrumented to enable the on-board computer and a variety of sensors to automatically monitor vehicle performance characteristics and to relate these to fuel consumption. Over many drivers, then, we will be able to develop typical driving behavior patterns and fuel efficiency curves related to those patterns. This information will be extremely useful to designers of both vehicles and roadways.

As a test driver your task is to drive in your normal fashion and obey all traffic laws. You will be directed to the beginning of the test route you are to drive and will be told which direction to go at each intersection. Directions to turn left or right or go straight at each intersection will be given to you as you approach the intersection. Some intersections will be controlled with a STOP sign, some with a YIELD sign, and a few will not have any control.

During the course of the test driving session you may hear various sounds from the computer. Do not be concerned with any of them! They indicate that the computer is either sampling certain sensors or that data is being transferred from the computer to the devices used to store the data. Unless you have questions regarding what you are supposed to do, please keep conversation to a minimum. We would like your full concentration on the driving task. We will answer any questions you have about the study after you have completed your run.

Do you have any questions?

Figure 11. Test driver instructions.

APPENDIX B: Perception-Reaction Times Associated with the Three PRT Definitions[1]

Table 15. PRT distributions--Case III four-way (PRT-2).

Time (s)	Frequency	Cum. Frequency	Percent	Cum. Percent
0.5	178	178	23.27	23.27
1	280	458	36.60	59.87
2	155	613	20.26	80.13
3	59	672	7.71	87.84
4	40	712	5.23	93.07
5	22	734	2.88	95.95
6	8	742	1.05	96.99
7	8	750	1.05	98.04
8	10	760	1.31	99.35
9	3	763	0.39	99.74
10	2	765	0.26	100.00

[1]The 0.5-second value shown in each of the tables was assigned to those intersection trials where the event starting the timing of the PRT interval, e.g., first head movement, occurred in the same sampling interval as the application of the accelerator.

Table 16. PRT distributions--Case III T (PRT-2).

Time (s)	Frequency	Cum. Frequency	Percent	Cum. Percent
0.5	65	65	18.79	18.79
1	111	176	32.08	50.87
2	89	265	25.72	76.59
3	36	301	10.40	86.99
4	22	323	6.36	93.35
5	9	332	2.60	95.95
6	6	338	1.73	97.69
7	5	343	1.45	99.13
9	2	345	0.58	99.71
10	1	346	0.29	100.00

Table 17. PRT distributions--Case III four-way (PRT-3).

Time (s)	Frequency	Cum. Frequency	Percent	Cum. Percent
0.5	134	134	26.85	26.85
1	180	314	36.07	62.93
2	95	409	19.04	81.96
3	33	442	6.61	88.58
4	29	471	5.81	94.39
5	15	486	3.01	97.39
6	5	491	1.00	98.40
7	3	494	0.60	99.00
8	5	499	1.00	100.00

Table 18. PRT distributions--Case III T (PRT-3).

Time (s)	Frequency	Cum. Frequency	Percent	Cum. Percent
0.5	53	53	20.54	20.54
1	92	145	35.66	56.20
2	63	208	24.42	80.62
3	23	231	8.91	89.53
4	13	244	5.04	94.57
5	6	250	2.33	96.90
6	6	256	2.33	99.22
7	1	257	0.39	99.61
9	1	258	0.39	100.00

Table 19. PRT distributions--Case III four-way (PRT-1).

Time (s)	Frequency	Cum. Frequency	Percent	Cum. Percent
0.5	435	435	25.60	25.60
1	581	1016	34.20	59.80
2	319	1335	18.78	78.58
3	152	1487	8.95	87.52
4	71	1558	4.18	91.70
5	57	1615	3.35	95.06
6	20	1635	1.18	96.23
7	14	1649	0.82	97.06
8	12	1661	0.71	97.76
9	7	1668	0.41	98.16
10	3	1671	0.18	98.35
12	1	1672	0.06	98.41
13	4	1676	0.24	98.65
14	1	1677	0.06	98.71
15	1	1678	0.06	98.76
16	1	1679	0.06	98.82
18	1	1680	0.06	98.88
19	1	1681	0.06	98.94
20	1	1682	0.06	99.00
21	2	1684	0.12	99.12
22	1	1685	0.06	99.18
25	1	1686	0.06	99.23
27	1	1687	0.06	99.29
29	2	1689	0.12	99.41
30	10	1699	0.59	100.00

Table 20. PRT distributions--Case III T (PRT-1).

Time (s)	Frequency	Cum. Frequency	Percent	Cum. Percent
0.5	147	147	18.89	18.89
1	263	410	33.80	52.70
2	165	575	21.21	73.91
3	83	658	10.67	84.58
4	44	702	5.66	90.23
5	29	731	3.73	93.96
6	10	741	1.29	95.24
7	4	745	0.51	95.76
8	3	748	0.39	96.14
9	3	751	0.39	96.53
10	2	753	0.26	96.79
12	1	754	0.13	96.92
13	1	755	0.13	97.04
17	2	757	0.26	97.30
18	1	758	0.13	97.43
19	1	759	0.13	97.56
20	2	761	0.26	97.81
21	1	762	0.13	97.94
22	2	764	0.26	98.20
25	1	765	0.13	98.33
26	2	767	0.26	98.59
27	1	768	0.13	98.71
28	2	770	0.26	98.97
30	8	780	1.03	100.00

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