Driver Response to Amber Phase of Traffic Signals

PAUL L. OLSON and RICHARD ROTHERY, Respectively, Senior Research Psychologist and Physicist, Research Laboratories, General Motors Corporation, Warren, Mich.

Observations of motorist response to the amber phase of traffic signals obtained at five intersections, representing three speed zones, are presented. The data give an estimate of the probability of stopping for vehicles as a function of their distance from the intersection at the onset of the amber phase of the traffic signal. The results lend no support to a popular hypothesis; that is, that drivers tend to "take advantage" of a long amber phase by treating it as an extension of the green. The results of the study are compared with other investigations pertaining to amber phase lengths and implications of this work for the design of amber phases are discussed.

• IN A PAPER, Gazis, Herman and Maradudin (1) discuss in considerable detail a problem associated with the amber signal light in traffic flow. This problem arises when a driver, confronted with an improperly timed amber light phase, finds himself in the position of being too close to the intersection to stop safely and too far from the intersection to proceed and pass through it completely before the red phase commences. By means of a theoretical discussion and observational data, Gazis et al. present criteria for the design of the amber light phase which would eliminate such "dilemma zones"; that is, they derive the following formula for τ_{min}, the minimum amber phase duration:

$$\tau_{min} = \delta_2 + \frac{V_0}{2a^*_2} + \frac{W + L}{V_0} \quad (1)$$

in which

δ_2 = reaction and decision-making time of the driver;
V_0 = approach speed of the vehicle,
W and L = intersection width and vehicle length, respectively, and
a^*_2 = constant rate of deceleration for the case where the vehicle attempts to stop in front of the intersection (in practice this constant deceleration represents the maximum average deceleration to which it is desirable or practical to subject drivers).

To use Eq. 1, assumptions must be made concerning this deceleration as well as the reaction-decision time of drivers. Despite the uncertainties regarding these parameters, τ_{min} undoubtedly provides a reasonable approximation of an adequate amber phase duration. When it is used as a criterion, comparison of observed and calculated amber phase duration indicates that many light cycles are improperly designed even for fairly high decelerations (~16 ft per sq sec), and for reasonable reaction times (~1.0 sec).

There is a problem involving amber signal duration, which could probably be resolved by extending the duration of the amber phase so that it was at least τ_{min}. One major difficulty in adopting this procedure is the contention of many traffic engineers that drivers tend to regard long amber phases as extensions of the green. The inference from this contention is that drivers farther from the intersection may be tempted to continue where otherwise they would have stopped. Because of this, a greater error may be introduced in their judgments, increasing the probability of their being caught in the intersection during the red phase of the light cycle. Of course, even if this contention is valid it still does not constitute an adequate reason for presenting drivers with an insoluble problem during amber cycles, particularly if the vehicle code is not compatible with physical reality. In light of this contention the authors investigated the behavior of vehicle operators at normal intersections, making observations on those drivers caught near the intersection at the moment the amber phase commences to determine in particular whether the behavior of motorists in this situation actually does change with significantly different amber phase durations.

TABLE 1

PROBABILITY OF CARS STOPPING AS A FUNCTION OF THEIR SPEED AND DISTANCE FROM SIGNAL AT ONSET OF AMBER[1]

Speed (mph)	Distance from Signal (ft)		
	0.50[2]	0.80[2]	0.95[2]
30	100	120	135
40	160	190	210
50	225	275	300

[1] Data from Webster (2).
[2] Probability of stopping.

Another study related to this problem was made by Webster (2). In that experiment drivers approached a mock-up light signal at specific speeds. As the vehicle approached the light which was set on the green phase, the vehicle itself, at fixed distances from the stop line, triggered the light to the amber phase. From this admittedly artificial situation Webster was able to construct a table giving the probability of stopping at different speeds for particular vehicle distances from the intersection when the amber phase commenced (Table 1).

If the contention that long amber phases are regarded as extensions of the green is correct, then instead of one probability of stopping curve (P_S) for a given speed of approach, there should in reality be a family of curves, one for each significantly different amber phase duration.

In light of the preceding discussion it would seem important to determine whether driver behavior changes as a function of altered amber phase lengths. One way this problem might be investigated is to determine the probability of stopping as a function of the distance from a particular intersection for two different amber phase settings. However, because it would require some time, perhaps a very long time, for individuals to become aware of a change of the amber phase and alter their response (if they ever do), an alternate procedure was used This technique involved comparison of pairs of intersections as similar as possible in their physical characteristics but differing appreciably in amber phase durations. This latter approach has one disadvantage in that if the two resultant curves differed, it could not be legitimately maintained that it was due to the amber phase.

PROCEDURE

Two items of information were necessary to obtain the desired P_S curves: (a) the distance of the vehicles from the intersection at the beginning of the amber phase, and (b) whether each vehicle stopped or proceeded through the intersection. It is assumed that the speed distribution for a given speed zone does not differ appreciably from one intersection to another. The position of the vehicles was recorded photographically by setting a 35-mm camera to cover an area some distance back from the intersection and manually tripping the shutter as the light turned to amber. Simultaneously, a written record was made of the vehicles that were in this region, whether they stopped or not, and their identification as to make or other obvious characteristics. Cars that turned or were moving conspicuously slower than the bulk of the traffic were not considered. If the behavior of a driver was in any obvious way influenced by other drivers his vehicle was also eliminated. Thus, for example, if a car stopped, all others behind it were not recorded, even if there was an opportunity to change lanes. Only free-running, relatively open traffic was considered.

TABLE 2

FREQUENCY OF OCCURRENCE OF DIFFERENT SPEEDS DURING 5-SEC TIME BLOCKS OF A GREEN PHASE

Speed (mph)	No of Cars	Frequency				
		0-5 Sec	6-10 Sec	11-15 Sec	16-20 Sec	21-25 Sec
56 8	8	—	—	2	4	2
48 7	37	—	8	15	10	4
42 6	106	3	12	33	37	21
37 9	115	5	11	22	30	47
34 1	115	2	13	20	35	45
31 0	42	—	9	7	6	20
28 4	11	—	3	3	4	1
26 0	2	—	—	1	—	1
24 3	6	1	—	4	—	1
22 7	1	—	—	—	—	1
21 3	2	—	—	1	1	—
20 0	1	—	—	—	1	—
Total	446	11	56	108	128	143
Mean speed		37 3	38 0	39 0	38 8	36 7

Recordings were made generally in the afternoon, sometimes in the morning, covering all periods of the day except rush hours where the density of traffic was usually such that queues were created that would not clear during the green phase.

At each of the several intersections studied about 300 usable measurements were obtained. These were distributed among eight to fourteen 20-ft intervals back from the intersection. For the purpose of consistency the reference point along the road being studied, from which the measurements of vehicle position originated, was always taken from a point on a line with the paved edge of the intersected road. On the basis of the fractional number of vehicles that stopped in each of these intervals it was possible to plot the desired P_s curves, using the midpoint of each interval as the reference distance. The data in this form are displaced toward the intersection by an amount equal to the distance covered by the vehicles during the time required for the camera operator to react to the amber onset. Accordingly, a correction was made by shifting the curves back from the intersection by a distance equal to the product of the mean speed in feet per second and a reasonable reaction time. The value used for this reaction time was 0.15 sec as given by Woodworth and Schlosberg (3) for this type of stimulus.

Three speed zones were investigated: 25, 40, and 55 mph. To ascertain whether the traffic was moving at comparable speeds at the intersections to be paired, speed checks were made at each by means of a Simplex time productograph, recording the time required for a vehicle to move through a trap of a known length. Only freely moving vehicles which did not stop or turn were considered. Because it seemed reasonable that traffic would be moving at different speeds past the trap at different phases of the green cycle the speed data at the first intersection were classified according to time during the green cycle in 5-sec intervals. These data are given in Table 2. The small differences in the different classes were far short of significance as tested by the extension of the Median test described by Siegel (4). Because of this, only the mean speeds were considered in subsequent cases.

RESULTS

The first comparison was made between two intersections on thoroughfares whose speed limits were posted at 40 mph. In each case the mean speed was fairly close to the posted speed limit, being 38.0 mph in one case and 36.4 mph in the other. The differences between these two mean speeds is really quite small. For example, using Eq. 1, they would have a τ_{min} differing by approximately 0.1 sec.

At the time the measurements were taken both amber phases had been unchanged for more than a year. Both roads were four lanes wide with grassy medians over 100 ft wide. Table 3 gives the significant parameters; amber phase duration, intersection width, speed limit, and observed mean speeds together with the theoretical τ_{min} as calculated by Eq. 1 for the approach speed of 40 mph assuming maximum desirable decelerations of 12 and 16 ft per sq sec and reaction times of 0.75 and 1.0 sec. A car length was taken as 17 ft. Table 3 shows that neither amber is adequate for

TABLE 3

COMPARISON OF CHARACTERISTICS OF TWO INTERSECTIONS POSTED AT 40 MPH

Comparison	a_2^* (ft/sec²)	δ_2 (sec)	Mound at 11 Mile	Stephenson at Lincoln
Amber phase (sec)			4 15	2 90
Cross-street width (ft)			28	36
Mean speed (mph)			38.0	36.4
τ_{min}(sec)[1]	12	0 75	5 07	5 41
		1 0	5 32	5.66
	16	0.75	4.00	4 25
		1 0	4 25	4 50

[1] Based on speed of 40 mph

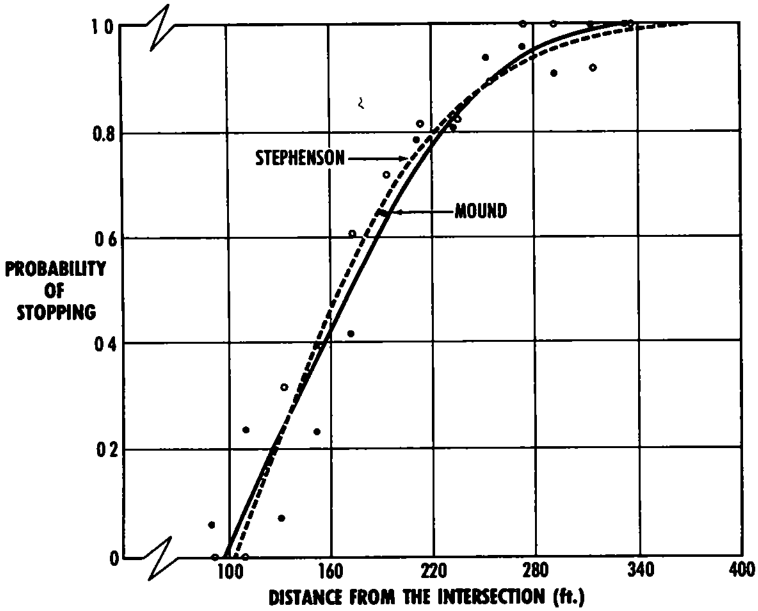

Figure 1. Comparison of probability of stopping for two intersections posted at 40 mph. Circles are points for Stephenson and solid dots for Mound intersection. Smooth curves are visual fit to data.

TABLE 4

PROBABILITY OF STOPPING DATA FOR TWO 40-MPH INTERSECTIONS

Mound				Stephenson			
Distance (ft)	No. Stopping	No. Not Stopping	P_s	Distance (ft)	No. Stopping	No. Not Stopping	P_s
92	1	15	0.06	94	0	17	0.00
112	5	16	0.24	114	0	20	0.00
132	2	26	0.07	134	7	15	0.32
152	5	16	0.24	154	8	13	0.38
172	8	11	0.42	174	11	7	0.61
192	13	7	0.65	194	18	7	0.72
212	19	5	0.79	214	23	5	0.82
232	13	3	0.81	234	20	4	0.83
252	16	1	0.94	254	27	3	0.90
272	23	1	0.96	274	29	0	1.00
292	20	2	0.91	294	21	0	1.00
312	23	0	1.00	314	12	1	0.92
332	11	0	1.00	334	18	0	1.00

reasonable decelerations or reaction times but the longer of the two is close to being satisfactory. Table 4 gives data for these two intersections, showing the number and percent of cars that stopped in each 20-ft interval. From these data the probability of stopping points was computed. These curves for both intersections are shown in Figure 1. The smooth curves represent a visual fit to the data.

TABLE 5

COMPARISON OF CHARACTERISTICS OF TWO INTERSECTIONS POSTED AT 25 MPH

Comparison	a^*_2 (ft/sec^2)	δ_2 (sec)	Gratiot at Robertson	Gratiot at Church
Amber phase (sec)			4.75	3.00
Cross-street width (ft)			30	30
Mean speed (mph)			32.9	31.0
τ_{min} (sec)[1]	12	0.75	3.65	3.65
		1.0	3.90	3.90
	16	0.75	3.20	3.20
		1.0	3.45	3.45

[1] Based on speed of 30 mph.

TABLE 6

PROBABILITY OF STOPPING DATA FOR TWO 25-MPH INTERSECTIONS

	Robertson			Church		
Distance (ft)	No. Stopping	No. Not Stopping	P_S	No. Stopping	No. Not Stopping	P_S
77	0	36	0.00	0	15	0.00
97	2	36	0.05	2	34	0.06
117	9	18	0.33	19	16	0.54
137	10	16	0.38	22	7	0.76
157	25	15	0.63	27	6	0.82
177	23	5	0.82	34	2	0.94
197	51	2	0.96	34	1	0.97
217	85	1	0.99	18	0	1.00
237	—	—	—	26	0	1.00
257	—	—	—	17	0	1.00

It is apparent that no point along the P_S scale do the curves differ by much more than a car length, and at the higher percentiles there is an overlap.

A second comparison was made between two intersections on thoroughfares whose speed limits were posted at 25 mph. At the time the study was made, these signals had remained unchanged for more than four years. In this case both intersections were on the same four-lane street, approximately ½ mi apart. Table 5 gives the significant parameters of the two intersections. In this case, the actual mean speeds at both intersections are in excess of the posted limit. Because of this the data should be considered as a better approximation of what would be expected for an approach speed of 30 mph rather than 25 mph.

Table 5 shows that not only is there a significant difference between the two amber phases but the longer one is longer than would be recommended on a basis of an application of Eq. 1. Table 6 gives the data for these intersections and Figure 2 shows the P_S curves.

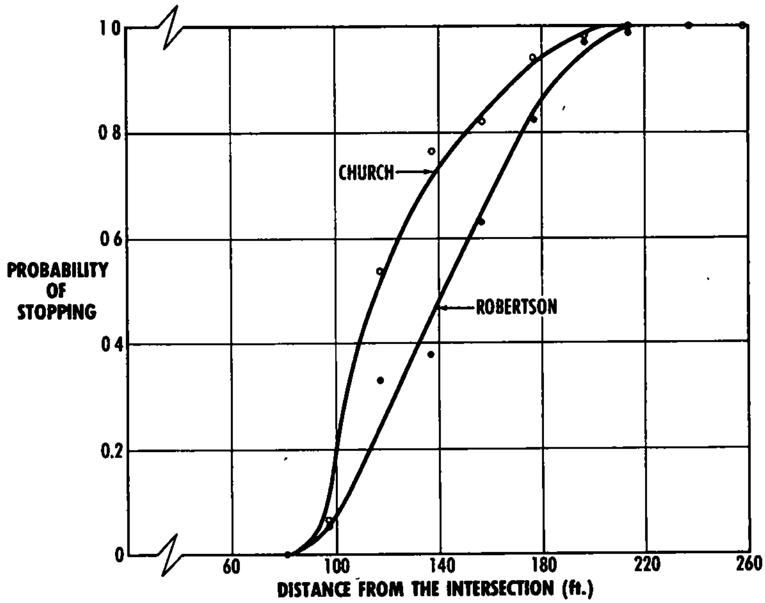

Figure 2. Comparison of probability of stopping for two intersections having mean speeds of approximately 30 mph.

The results of the first two comparative phases of this study indicate that driver behavior does not change significantly when faced with longer amber phases. For this reason the investigation of the higher speed zone was done at only one intersection, with no effort being made to pair it with another. Table 7 gives the significant parameters of the intersection and Table 8 gives the stopping data; the P_S curve is shown in Figure 3. Figure 4 shows representative P_S curves drawn for the 30- and 40-mph speed zones as well as the curve for the 50-mph intersection.

TABLE 7

CHARACTERISTICS OF AN INTERSECTION POSTED AT 55 MPH

Characteristic	a^*_2 (ft/sec^2)	δ_2 (sec)	Value
Amber phase (sec)			4 20
Cross-street width (ft)			38
Mean speed (mph)			48 0
τ_{min} (sec)[1]	12	0.75	6.09
		1 0	6 34
	16	0.75	4 95
		1 0	5 20

[1] Based on speed of 50 mph.

ANALYSIS AND CONCLUSIONS

From Figures 1 and 2, comparing two sets of intersections, it would appear that there is no significant behavioral change in drivers associated with different amber cycle lengths. If the contention that drivers regard amber phases as extensions of the green were true, the P_S curve would be displaced a distance approximately equal to the difference in cycle length multiplied by the mean velocity of the traffic on the thoroughfare considered. For example, in the first comparison, a vehicle traveling at the posted speed limit of 40 mph would

TABLE 8

PROBABILITY OF STOPPING DATA FOR A 50-MPH INTERSECTION

Distance (ft)	No Stopping	No Not Stopping	P_S
221	6	58	0 09
241	13	26	0.33
261	13	21	0.38
281	17	20	0.46
301	25	15	0.63
321	31	10	0 76
341	25	5	0.83
361	24	9	0 73
381	21	2	0.91

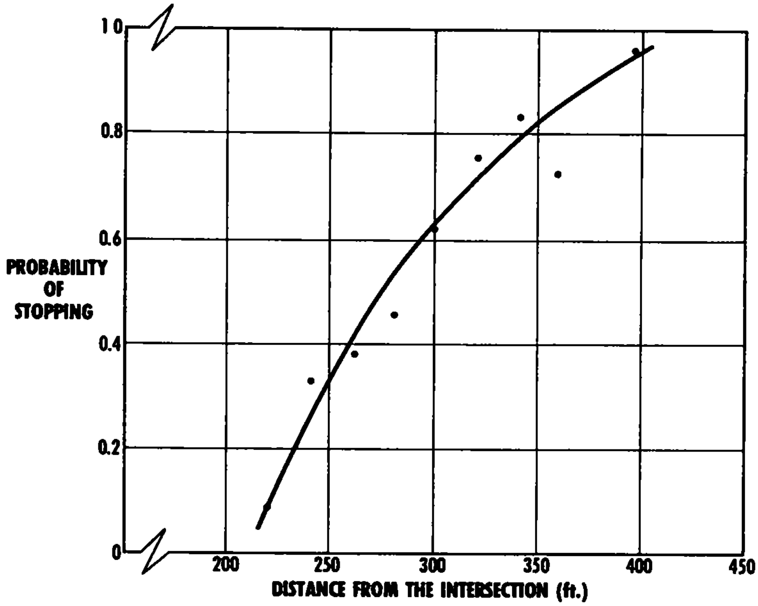

Figure 3. Probability of stopping for intersection where mean speed is approximately 50 mph.

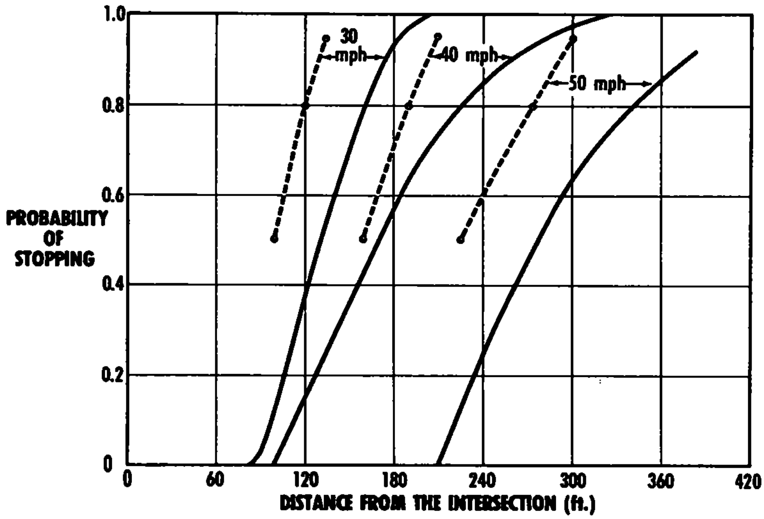

Figure 4. Representative curves for probabiliby of stopping for three speed zones. Dotted curves based on Webster data (Table 1).

travel approximately 80 ft in the 1.25-sec time difference between the two amber phase durations. The two curves of Figure 1 are displaced but a fraction of this distance. Similarly, in the second comparison, a vehicle traveling at the observed mean speed of 30 mph would travel a distance of 77 ft in the 1.75-sec time difference between these two amber phase durations. Again, the curves of Figure 2 are displaced but a fraction of this distance.

In comparing the representative curves of the three different speed zones of Figure 4, they are displaced from each other significantly for the different speed zones. The distance is approximately 40 ft at the 50th percentile point between the curves for the 30- and 40-mph speeds and approximately 105 ft between the curves for the 40- and 50-mph speeds, again at the 50th percentile point. In this figure Webster's data have also been plotted for comparison. For a given speed and distance his probability of stopping is considerably greater than for the same values in this investigation. For example, for an approach speed of 50 mph, Webster's stopping distance at the 50th percentile point is given as 225 ft. This would require an average deceleration of 17.7 ft per sq sec for drivers having a reaction time of 1.0 sec and would require an average deceleration of 15.8 ft per sq sec for drivers having a reaction time of 0.75 sec. These rather high decelerations can probably be attributed to the motivation and orientation of Webster's subjects.

In Figure 4 the stopping curve for the 50-mph zone is displaced from the stopping curves of the second comparison by approximately 105 ft at the 50th percentile level. From this displacement the apparent average deceleration to which drivers are willing to subject themselves is 12.9 ft per sq sec (assuming a 0.75-sec reaction time) at this level. Thus, the results seem to indicate that drivers allow themselves an added stopping distance for higher speeds to that they can stop comfortably with a deceleration in the range of 12 to 14 ft per sq sec.

The data in Tables 4 and 6 make possible an interesting comparison. By multiplying the length of the amber phase by the mean speed and subtracting the width of the intersection and the length of a typical vehicle, it is possible to calculate the average maximum possible distance a car, traveling at the mean speed, can be from the intersection at the beginning of the amber phase and still clear the intersection without accelerating. For example, using the data in Table 3, cars approximately 200 ft or more back from the intersection having the longer amber (Mound) could not have cleared in time. In the case of the shorter amber (Stephenson), cars approximately 100 ft or further from the intersection could not have cleared. Of the cars beyond this cut-off distance, 9 percent did not stop at the intersection having the long amber and 28 percent failed to stop at the shorter amber. In the case of the shorter amber light the dilemma zone is of considerable length. Indeed, assuming a reasonable desirable deceleration of 12 ft per sq sec and a fair reaction time of 1.0 sec, then the dilemma zone is about 100 ft. In comparison, the longer amber has a dilemma zone of 10 ft. It seems significant that of the 28 percent who did not stop at the shorter amber and who could not have cleared the intersection, 82 percent were in this 100-ft dilemma zone. One might conjecture that, if the shorter amber at Stephenson was extended to 4.2 sec, there would be approximately an 82 percent decrease in the number of vehicles that would not clear the intersection before the red phase. Furthermore, the fractional number of motorists who did not stop and who could not have cleared the intersection would then be essentially the same for these two intersections.

If driver behavior does not change as a function of amber phase durations, it should be possible to establish realistic amber phase settings on the basis of actual driver behavior. Thus one might decide that an amber phase should be of such a length that no more than perhaps 5 percent of the vehicle operators who do not stop when faced with the amber light do not clear the intersection before the red phase. Thus one could refer to a P_S curve for the appropriate speed, determine how far back from the intersection the 95th percentile point is, and use the following modification of Eq. 1:

$$\tau_{min} = \frac{A+W+L}{V_o} \qquad (2)$$

in which

A = distance from the intersection at which the desired percentile occurs; and

W, L, and V_o = same as in Eq. 1.

For example, if the 95th percentile cutoff is used, the prescribed τ_{min} for the lower speed intersection (calculated at the actual mean speed of 32 mph) would be 5.25 secs, τ_{min} for the midspeed intersections (calculated at the actual mean speed of 38 mph) would be 5.39 secs and the τ_{min} for the high speed intersection (calculated at the actual speed of 48 mph) would be 5.57 secs. The small differences between these recommendations is noteworthy. It is probably feasible to use an essentially constant amber phase length for a large range of speed limits, making small changes only for unusually large cross-street widths.

This investigation of the behavior of motorists faced with the onset of an amber signal light has been a continuation of the theoretical analysis and observations reported by Gazis et al (1). This study was made to seek possible behavioral trends in this decision making problem that all too frequently occurs in every day traffic. The data are limited, mainly due to the extended effort required to obtain the kind of information necessary to make the comparisons presented. However, from these data the following conclusions can be drawn:

1. Driver behavior does not seem to change as a function of different amber phase durations.
2. The amber phases observed are too short as measured either by a criterion of driver behavior or a dilemma zone.
3. A constant amber phase of about 5.5 secs would be practical for a wide range of speed zones, with possible variations made to allow for extra wide cross-streets.

That drivers seem to react about the same to ambers of different duration is perhaps a result of confusion resulting from the fact that the average motorist simply does not know how long the typical amber phase is, a situation further confounded by the fact that there is no standard method of setting the length of the amber duration. Thus, the motorist, under these conditions may not try to react differently though the possibility exists that he would were ambers lengthened and standardized. Unless there exists a locale unknown to the authors where amber phases are characteristically longer than what appears to be "normal," this possibility cannot be checked out.

ACKNOWLEDGMENTS

The authors wish to thank R. Herman and J. B. Bidwell of the General Motors Research Laboratories for valuable discussions and constructive comments regarding this paper, as well as for their continued interest during this work. One of the authors (RR) also wished to express his gratitude to D. Gazis with whom he had several interesting discussions.

REFERENCES

1. Gazis, D.C., Herman, R., and Maradudin, A.A., "The Problem of the Amber Signal Light in Traffic Flow." Operations Research, 8:112-132 (1960).
2. Webster, F., "Progress of Work on a New Type of Controller for Traffic Signals on High Speed Roads." Road Research Laboratory, Research Note, RH/3634 (Dec. 1959).
3. Woodworth, R.S., and Schlosberg, H., "Experimental Psychology." Holt (1960).
4. Siegel, S., "Nonparametric Statistics." McGraw-Hill (1956).

Discussion

H.J. KLAR, Chief, Bureau of Engineering and Planning, New Jersey Division of Motor Vehicles, Bureau of Traffic Safety, Trenton—Although it is recognized that the motorist approaching a traffic signal at the beginning of the amber phase has a difficult decision to make, the writer fails to see the merit of using the same length of amber ($5\frac{1}{2}$ sec) regardless of vehicle approach speed.

Using the standard stopping distance formula ($S = \frac{V^2}{30f}$) on a level surface with f = 0.5 and allowing 2 sec for perception, intellection, emotion, and volition, one can readily calculate and obtain the following over-all stopping distances:

MPH	Ft
30	140
40	226
50	317
60	416

Calculating the distances traveled at the several speed, respectively, for 3, 4, 5, 6, and 5½ sec, the following are obtained:

Speed (mph)	Distance (ft) for				
	3 Sec	4 Sec	5 Sec	6 Sec	5½ Sec
30	135	—	—	—	248
40	—	240	—	—	330
50	—	—	375	—	413
60	—	—	—	528	484

If the commonly used "rule of thumb" for amber periods of 3 sec for 30-mph approach speeds, 4 for 40, 5 for 50, and 6 for 60 is applied and the over-all stopping distances for these speeds are compared with the corresponding distances traveled for the respective number of seconds, it is apparent that the "rule of thumb" values approximate or are on the conservative side of providing sufficient distance for a motorist to stop within the allotted distances if his attention is not diverted from the signal indications and assuming reasonably good friction between the tires and the pavement.

On the other hand, if 5½-sec amber periods were used for the 30-, 40-, and 50-mph approach speed locations, the distances traveled during this time interval would be considerably higher than needed. For 60-mph approach speed areas, the 5½-sec amber would be very good.

In the case of large intersections where the distance from the stop line to the collision point exceeds 60 or 70 ft, a short "All Red" period has been used to provide additional clearance time instead of increasing the length of the amber interval.

If the amber period is increased beyond what is normally needed for a given location, many drivers will ride the amber while some will conscientiously stop with the result that the rear-end collision potential increases.

At several selected locations throughout the State, a pre-warning device has been used to indicate to the motorist that the traffic signal will be red when he arrives at the signalized intersection.

This device normally displays an illuminated message "Signal Ahead" during the bulk of the green phase. "X" seconds before the red phase to that roadway, the sign message flashes alternately the words "Red" and "Signals Ahead." The alternating message continues to flash until the expiration of that red phase when it returns to the steady message "Signal Ahead."

In this way, fairly good information is given to motorists at all points in the signal sequence of operation at distances 500 to 1500 ft before the signal. Incidentally, the sign can be seen at much greater distances by motorists who are familiar with the operation.

It might be possible to help the motorist judge his distance from the white stop line by painting a yellow line transversely across the pavement at appropriate points commensurate with the approach speeds. The point at which the yellow line might be painted could be considered the "brake point." A motorist approaching a traffic signal would prepare to stop if he had not reached the "brake point" when the signal went amber. Conversely, if the motorist were between the "brake point" and the intersection, he would continue on through the intersection and would not be considered to be in violation of the signal, assuming, of course, that he was traveling near the normal approach speed.

The following table of distances is suggested for determining the "brake point":

Speed (mph)	Distance Before Intersection (ft)
30	140
40	240
50	360
60	470

Longer distances than necessary are used in this table for the higher speeds to provide a greater safety factor at these speeds. It is probably more likely for a motorist traveling at the higher speeds not to notice a traffic signal so soon because of the generally much greater spacing of signalized intersections. Another factor is that the vehicle brakes are more apt to cause a vehicle to swerve because the brakes have not been applied for some time, thereby requiring longer stopping distances. A third factor would be the greater difficulty of a motorist judging his distance from the intersection relative to his ability to stop or to continue on through.

To help the average motorist to understand the purpose of the yellow line, it might be well to erect a sign or signs at the end or ends of the yellow line bearing the message "Brake Point."

PAUL L. OLSON and RICHARD ROTHERY, Closure—The authors wish to reiterate that the main purpose of the study was to provide data on actual performance of drivers, with the hope in mind that amber phase durations could be adjusted to suit human performance. On the other hand, the writer quotes a frequently employed "rule of thumb" for determining stopping distances. The authors have two comments to make regarding this rule: (a) a rule of thumb, based on what seems reasonable to expect from humans, can hardly be used as an argument against actual measurements of what they do; (b) this rule of thumb assumes an average deceleration of approximately 16 ft per sq sec. On the basis of the study this assumption appears to be unreasonable. More specifically, another study (1) has shown that drivers in a variety of traffic situations brake with a deceleration of 16 ft per sq sec or more less than 1 percent of the time.

The common assertion that when the amber period is increased beyond what is normally provided, many drivers will ride the amber while some will conscientiously stop with the possible result that rear-end collision potential increases was subject to specific scrutiny in the study. It will be recalled that no significant differences in the location of the end points of the probability of stopping curves were found when comparing intersections having the same speeds but different amber phase durations. This is the only evidence the authors know of that bears directly on this question and it stands in direct refutation of the popular notion.

There seems to be some confusion resulting from the example used in trying to indicate how the probability of stopping curves could be employed to set amber phases. The figure of 5.5 sec results from selecting a cutoff at the 95th percentile. The selection of percentile cutoffs is completely arbitrary. The important point is that information such as that obtained from probability of stopping data makes it possible to estimate what percent of the drivers who elect to proceed through the intersection will not clear the intersection before the signal turns red.

The amber brake line suggested by the writer would undoubtedly provide added information. It might possibly improve the situation. However, for reasons indicated earlier, it certainly should not be based on a deceleration as high as that suggested.

In addition, there exists the possibility that the use of such a stop line would create unique problems under conditions where the road surface is slippery or to drivers moving slower than the speed limit. This could be subject to investigation and probably should be before such a system were widely employed.

The all-red clearing period that is being used in some parts of the country is potentially valuable and might be one solution to the amber light problem. However, if it is to provide a legitimate clearing phase a reinterpretation of ordinances would be required in many areas so that persons in the intersection during the all-red period would not be in violation.

REFERENCE

1. Olson, P. L., and Bauer, H. J., "Deceleration Forces in Normal Driving." General Motors Research Laboratories Tech. Memo., pp. 24-611 (1960).