SPEED PROFILES APPROACHING A TRAFFIC SIGNAL

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The objective of this study was to examine and compare the speed profiles of traffic approaching a traffic signal under six different signal displays. Detector loops were installed along one approach to a rural traffic signal installation. Detector actuations, signal indications, and timing information were recorded at a remote observation point by using a 20-pen operation recorder. Observations were made of lone vehicles approaching the traffic signal location. The speed profiles observed under each signal display were summarized and compared with the speed profiles under the other signal displays. Drivers at the study location entered the intersection more cautiously with a green traffic signal indication or a flashing yellow indication than they did with no signal installed. They did not speed up when signal control was changed from regular stop-and-go operation to flashing operation. Approaching a red signal indication, drivers did not begin to slow down until they were approximately 500 ft from the signal. Under all other signal displays, drivers generally maintained their speed as they approached the signal location and entered the intersection.

•FOR efficient design and operation of safe traffic signal installations we must understand the responses of drivers to various traffic signal indications. Although numerous studies dealing with certain traffic response characteristics, such as starting delays and headways, have been conducted, few studies have attempted to examine the speed profiles of vehicles approaching a traffic signal under various signal displays.

Important questions related to the speeds and speed profiles of vehicles approaching traffic signals include the following: How do drivers respond to different signal displays? When do they speed up? When do they slow down? When do they maintain their speed? How far in advance of the signal do drivers respond to the signal? Do drivers speed up when signal control is changed from stop-and-go operation to flashing operation? Does the installation and operation of a flashing beacon cause drivers to approach the location more cautiously; that is, do drivers slow down when approaching a flashing beacon?

Past studies of these questions are considered to be inconclusive by the author for the following reasons: Some of the studies failed to provide adequate control over the variations in speed with time; some studies employed coarse data collection methods and permitted the observer to unconsciously influence the recorded speed measurements; other studies compared speeds at only one or two specific points on the approach rather than determining the speed profile over the length of the approach.

FIELD STUDY

The site selected for this research was one approach to a rural, right-angle, four-way intersection in central Pennsylvania. The study approach carried one lane of traffic in each direction. The speed limit along the test approach was 55 mph. The average daily traffic volume at the test site was approximately 1,200 vehicles. Visibility of the traffic signal installed at the intersection was restricted to 1,200 ft by a change in grade.

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The land use on all four corners at the intersection was agricultural; this land use provided good visibility of other traffic near the intersection. The signal installation consisted of dual 8-in. signal indications; the installation conformed to state and national standards.

A series of 14 detector loops were installed in grooves cut in the pavement along the approach. The first loop was located 1,800 ft in advance of the intersection. Loops were spaced at 150-ft intervals with the last loop located 150 ft beyond the intersection. None of the loops was noticeable by approaching drivers. Detector actuations were transmitted by wire to a remote point of observation. Figures 1 and 2 show the plan and profile of the test approach.

A 20-pen operation recorder was employed to make a master record of signal indications, vehicle detections, timing pulses, and identification codes. Figure 3 shows the chart record produced during a demonstration run. The identification of each chart marking has been added to the illustrated record. The accuracy of the chart record and supplementary chart processing equipment was evaluated; the measured trap times were found to be accurate within $\frac{1}{20}$ sec 95 percent of the time. Therefore, by using this method of speed determination, the speed of a vehicle traveling at 50 mph could be determined to an accuracy of ±0.8 mph 95 percent of the time. Also, speeds could be determined without being influenced by human limitations. This method also permitted the entire speed profile of any given vehicle traveling along the approach to be determined.

Six specific signal displays were selected for this study. Four of these displays are shown in Figure 4 and are described as follows:

1. A green signal indication from the moment the signal first became visible until the vehicle reached a point approximately 900 ft in advance of the signal, at which point a red signal indication was given (preceded by a yellow clearance period), referred to as the green-red display;
2. A red signal indication until the signal was reached, referred to as the red display;
3. A red signal indication from the moment the signal first became visible until the vehicle reached a point approximately 900 ft in advance of the signal, at which point a green signal indication was given, called the red-green display; and
4. A green signal indication during the entire approach, called the green display.

The timing of the signal controller was synchronized with the approach of each vehicle selected for observation. This synchronization was accomplished by using the offset circuit to brake the cycle unit drum at the advance setting from the desired arrival point. As the observed vehicle passed loop 2, the brake circuit on the cycle unit was automatically released, thereby establishing the desired relationship between the signal timing and the approaching vehicle.

The fifth signal display consisted of flashing operation with traffic on the test approach receiving a flashing yellow signal indication, referred to as flashing yellow. The sixth display consisted of no signals at all. For the no signal display, the signal heads, span wire, and cables were removed from the site. Traffic control at the intersection reverted to two-way stop control with the test approach located on the through street. Observations with this display were made 1 month after the signals were removed to allow drivers time to adjust to the new intersection control.

For all six signal displays, observations were made on lone vehicles that did not turn at the intersection. Vehicles were selected randomly from the traffic stream. A vehicle was considered lone if it was separated from every other vehicle traveling in its direction by at least 600 ft (approximately a 10-sec headway preceding and following the observed vehicle). Observations for all six signal displays were made on weekdays during the daytime when the weather was clear or cloudy and the pavement was dry.

To control the variations in traffic speeds with time and to provide an equivalent basis for comparing the speed profiles observed with each of the six signal displays, we selected for inclusion in the study only those vehicles that had an initial speed of from 40 to 45 mph, as measured between loops 2 and 3 (trap 2). This qualifying speed was measured before the drivers could see the traffic signal indication at the intersection ahead.

Figure 1. Test site.

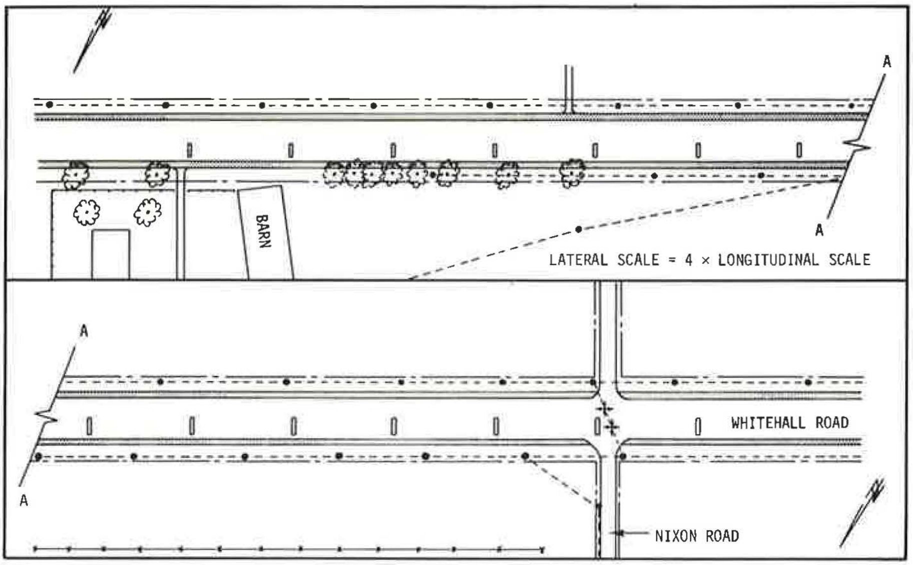


Figure 2. Test approach.

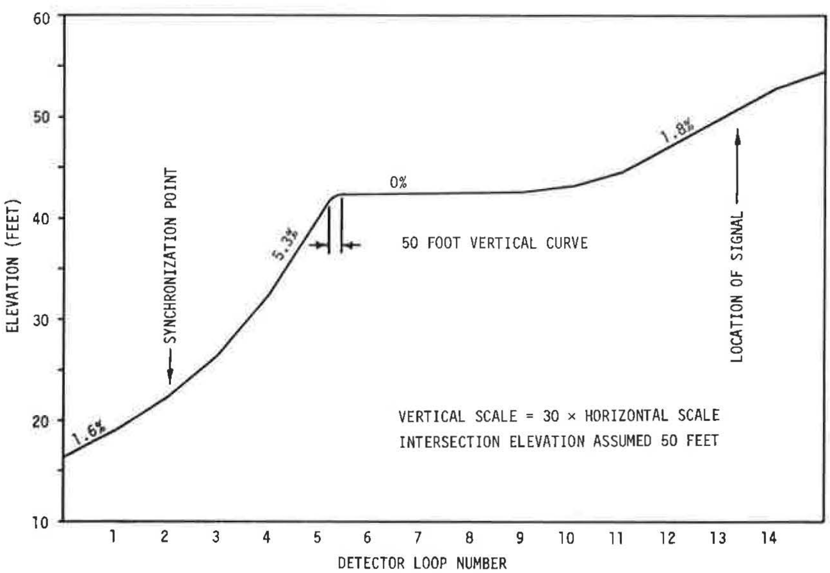
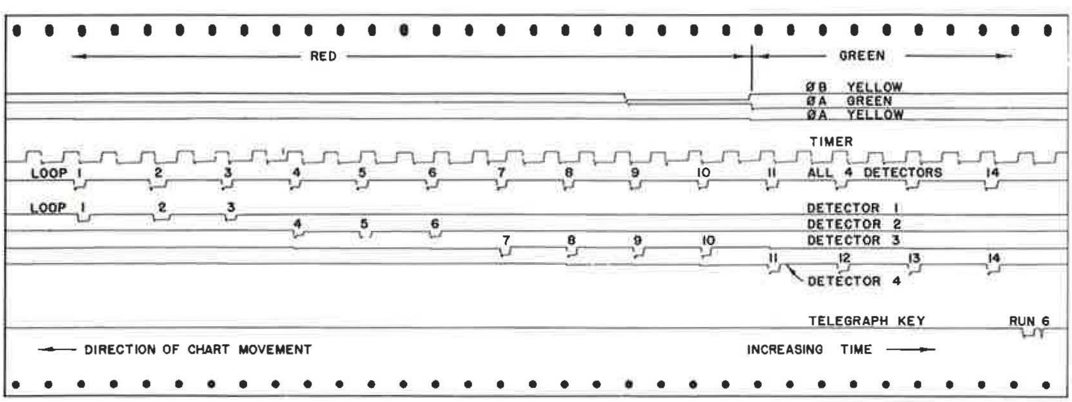


Figure 3. Operation recorder record of a demonstration run.



ANALYSIS

The markings recorded on the operation recorder charts for each observation were converted to coordinates and punched into data-processing cards. A Benson-Lehner model Oscar F film-chart reader and digital converter were used to automatically process the operation recorder records. In using this equipment, one merely positions a movable cross hair directly over the desired point on the chart and presses a button. The equipment then automatically determines the numerical coordinate of that point and punches the coordinate into a data-processing card.

An IBM 360 computer was used to edit the cards. The editing process included a check for errors in keypunching and a check for irregularities and inconsistencies in data speed and travel characteristics.

The time required to traverse the 150-ft distance between successive loops was converted to a speed that was assumed to be the actual spot speed of the vehicle at a point midway between the two loops. A single observation consisted of 13 successive trap speeds for one vehicle.

The individual speed profiles within each signal display condition were observed to be similar to each other. Accordingly, an average speed profile was computed for each of the six signal displays. Each point of the average speed profile was determined by averaging the individual trap speeds for each trap.

FINDINGS

Figure 5 shows the six average speed profiles, and Table 1 gives a summary of the average speeds and standard deviations. The following are specific findings based on Figure 5 and Table 1:

1. All six average speed profiles prior to trap 5 were essentially the same. The maximum difference between any two speed profiles in this area was 1.2 mph, which is not statistically significant. This finding indicates that the initial speeds were the same for all six sets of data.
2. All six average speed profiles exhibited a statistically significant reduction in speed at trap 5. This decrease was expected, inasmuch as trap 5 corresponds to the location of an abrupt vertical curve (Fig. 2). Prior to reaching trap 5, approaching drivers could not see the signal indications.
3. For the four signal displays that did not require approaching traffic to stop, red-green, green, flashing yellow, and no signal, the average speeds immediately prior to entering the intersection were slightly lower than the immediately preceding speeds. For the green display, the magnitude of this speed reduction, 2.4 mph over a 450-ft distance, was statistically significant. For the other three average speed profiles, the magnitude of the speed reduction was not statistically significant.
4. For the preceding four signal displays, the no signal display had a significantly higher intersection speed than the other three displays. This finding indicates that the operation of a flashing beacon or a traffic signal at this location caused drivers to approach the intersection more cautiously; that is, the drivers did slow down. The reduction in speed was between 3 and 4 mph.
5. A comparison of the average speed profile for the green display against the average speed profile for the flashing yellow display indicated that the two profiles were at no point significantly different. This finding indicates that drivers did not speed up when signal control was changed from stop-and-go operation to flashing operation.
6. Traffic approaching the red display at a speed of about 40 mph began slowing down approximately 150 ft after the red signal indication first became visible. The magnitude of this speed reduction was slight (less than 2 mph over a 500-ft distance) until a point approximately 500 ft in advance of the signal was reached, at which point the rate of deceleration increased significantly.

DISCUSSION OF FINDINGS

It is generally believed that the installation and operation of a traffic signal or flashing beacon will cause drivers to slow down and approach a location more cautiously than

Figure 4. Four signal displays studied.

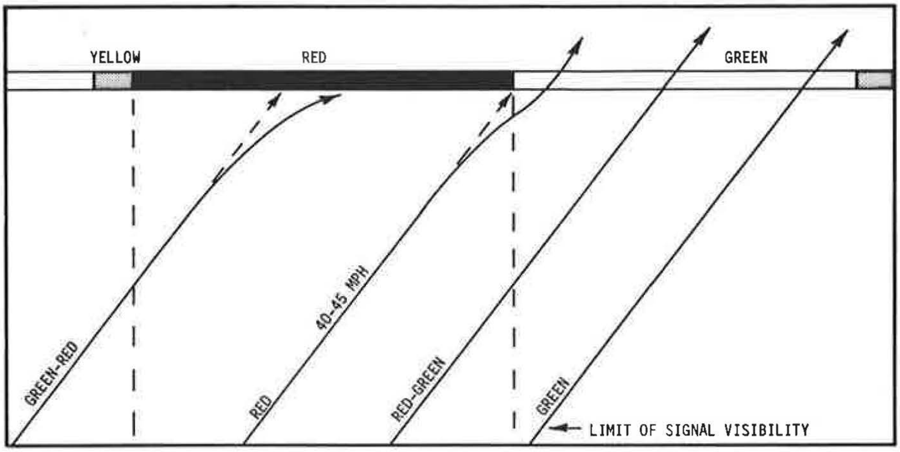
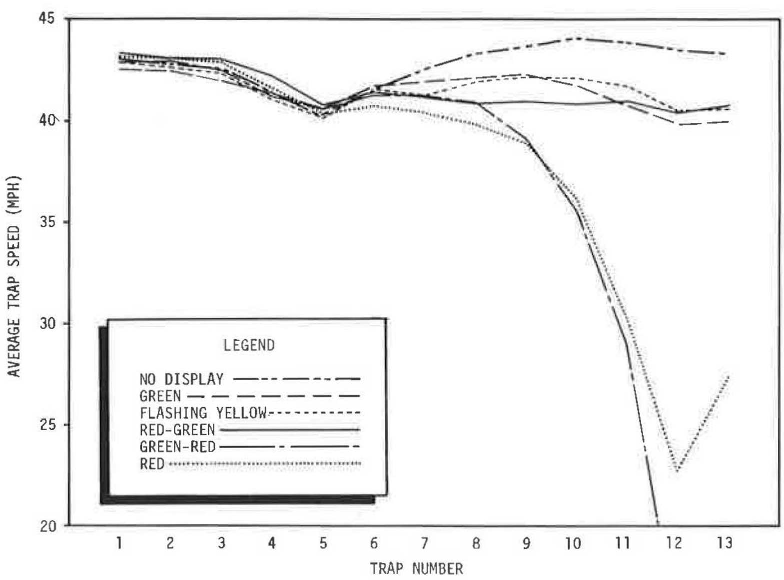


Table 1. Average speed profile characteristics.

Signal Display	Number Observed	Trap Number 1	2	3	4	5	6	7	8	9	10	11	12	13
Average speed (mph)														
Green-red	22	42.8	42.9	42.4	41.1	40.6	41.3	41.2	40.9	39.1	35.6	29.1	—	—
Red	17	43.2	43.0	42.9	41.6	40.3	40.7	40.4	39.8	38.9	36.1	30.3	22.7	27.3
Red-green	13	43.0	43.0	43.0	42.2	40.7	41.4	41.1	40.8	40.9	40.8	40.9	40.3	40.7
Green	18	42.5	42.4	41.9	41.3	40.6	41.7	41.9	42.1	42.2	41.7	40.7	39.8	40.0
Flashing yellow	17	42.8	42.6	42.3	41.0	40.1	41.5	41.2	41.9	42.1	42.1	41.7	40.5	40.5
No display	28	42.7	42.6	42.5	41.2	40.3	41.5	42.6	43.4	43.7	44.1	43.9	43.5	43.3
Standard deviation														
Green-red	—	1.3	1.3	1.4	1.4	1.8	2.1	2.1	3.0	4.1	5.4	6.8	—	—
Red	—	1.3	1.4	1.8	1.6	1.7	2.5	3.3	4.2	4.8	4.6	3.4	4.7	4.9
Red-green	—	1.7	1.8	2.0	2.4	2.6	2.7	3.6	4.2	4.6	3.8	3.6	4.3	5.3
Green	—	1.6	1.5	1.4	2.3	2.9	3.0	3.2	3.3	3.3	3.6	3.8	3.7	3.5
Flashing yellow	—	1.6	1.8	2.1	2.1	2.5	2.4	2.6	3.2	3.2	3.0	3.6	5.1	5.5
No display	—	1.4	1.5	1.6	1.7	2.1	2.4	2.4	2.7	3.2	3.7	3.4	3.5	3.6

Figure 5. Average speed profiles of traffic having initial speeds between 40 and 45 mph.



they would without such devices. Although the findings of this study support that conclusion with statistically significant data, the magnitude of the speed reduction, from 3 to 4 mph, may be considered to be of little practical significance. The significance in this finding is not in the magnitude of the speed reduction but in the increased degree of driver alertness and caution created by the device, as suggested by the fact that there was a decrease in speed.

It may seem unusual that with the four nonstop signal displays, green, red-green, flashing yellow, and no display, drivers generally did not slow down immediately in advance of the signalized intersection. The maximum speed reduction observed in all four average speed profiles was 2.4 mph over a 450-ft distance. This speed reduction is equivalent to a uniform deceleration rate of approximately $\frac{1}{100}$ ft/sec^2. Because the ground in the vicinity of the intersection was essentially flat, drivers approaching the signal could see across the corners of the intersection and observe that there was no conflicting traffic on the cross street, as was almost universally the case. Under these conditions, drivers apparently saw no need for slowing down in advance of the intersection. It is believed that a substantial speed reduction might have occurred had there been more cross traffic.

In approaching the red signal display, drivers could first see the red signal from a distance of approximately 1,200 ft. That they saw the signal at this distance is indicated by the fact that the red display speed profile significantly deviates from the no display speed profile soon after this point is reached. However, drivers did not begin to slow down for the red signal until they reached a point much closer to the intersection. They may have expected the signal indication to change to green before they reached the signal. In any case, they tended to hold their speed until reaching a point at which they were forced to decelerate. The distance at which forced deceleration begins varies with speed; in this case, the speed was approximately 40 mph, and forced deceleration began at approximately 500 ft in advance of the intersection. The resulting deceleration was equivalent to a uniform rate of approximately 4 ft/sec^2. The same deceleration rate was also observed for the green-red display.

This finding suggests that drivers considered a deceleration rate of approximately 4 ft/sec^2 to be the most comfortable rate. If they had preferred a more gradual rate, they would have begun forced deceleration earlier. If they had preferred a more abrupt rate, they would have waited longer before decelerating.

It has been claimed that traffic signals should not be placed on flashing operation when traffic volumes get low because flashing operation encourages drivers to drive faster (1). The average speed of all traffic approaching a flashing yellow signal would obviously be higher than the average speed of all traffic approaching the same signal with the stop-and-go operation of regular signal control; however, do drivers really approach a flashing yellow indication faster than they approach a green indication?

The findings of this study indicate that there was no significant difference in the speed profiles of traffic approaching a flashing yellow signal indication as compared to a green signal indication at any point along the 1,950 ft of roadway studied. It is not known whether these findings would apply to other locations. The major point of this finding is that serious consideration might advantageously be given to a careful study of the relative advantages of both regular and flashing signal control.

CONCLUSIONS

As a result of this study, the following conclusions were reached for the study location:

1. The installation and operation of a flashing beacon caused drivers to approach the intersection more cautiously than they did without the flashing beacon.
2. The installation and operation of a traffic signal caused drivers to approach the intersection more cautiously than they did without the signal.
3. Drivers did not approach a flashing yellow signal any differently than they approached a green signal. Drivers did not speed up when signal control was changed from stop-and-go operation to flashing operation.

4. Drivers approaching a red signal indication at a speed of approximately 40 mph did not substantially begin to slow down until they were 500 ft from the signal. The resulting deceleration was equivalent to a uniform rate of approximately 4 ft/sec^2.

5. When approaching this intersection with a green, flashing yellow, or no signal display, drivers generally did not slow down but tended to maintain their speed as they entered the intersection.

ACKNOWLEDGMENTS

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REFERENCE

1. Taylor, S. S. Means of Improving Traffic Signal Systems. Proc., Institute of Traffic Engineers, Wash., D.C., 1962, p. 70.