MEANING AND APPLICATION OF COLOR AND ARROW INDICATIONS FOR TRAFFIC SIGNALS

Ralph W. Plummer and L. Ellis King, West Virginia University

The Manual on Uniform Traffic Control Devices for Streets and Highways sets forth the conditions under which combinations of signal colors and turn arrows should be used at signal-controlled intersections. These recommendations have been generally accepted and complied with except in the case where a left-turning movement at an intersection is to be terminated while the through movement continues. In many instances, due to the physical limitations of an intersection or for reasons of economy, it is difficult to comply with this standard. Present practice at such locations is to mount a fourth lens displaying a turn arrow either on the through face or adjacent to it. Installations such as this result in a wide variety of clearance interval indications. This research project was designed to develop a standard for this situation. A literature review and mailed questionnaire were employed to determine present practices. A controlled laboratory study, utilizing both color movies and color slides, investigated 19 signal indications for their effectiveness in conveying their intended message to the driver. The collection of accuracy and reaction time data was analyzed by an analysis of variance and the Newton-Keuls test. Four of the indications proved superior and were tested further under actual field conditions. Based on the analysis of the driver performance data recorded in the field study, a single indication was recommended.

•SATISFACTORY RESULTS from traffic signal operation require a uniform understanding of signal color and arrow indications. The Manual on Uniform Traffic Control Devices for Streets and Highways (17) sets forth the conditions under which combinations of signal colors and turn arrows should be used at signal-controlled intersections. Recommendations contained in the Manual have been generally accepted and complied with; however, there is one notable exception, the case in which a turning movement at an intersection is to be cut off while the through movement continues. Present practice at such locations is to mount a fourth lens displaying a turn arrow either on the through face or adjacent to it. Installations such as this result in a diversity of clearance interval indications. Although this practice is widespread, it does not conform to the existing standard and has been a matter of some concern to various interested persons and groups. In this regard it was recommended as early as September 1966 in the report from the Traffic Control Devices Workshops sponsored by the Institute of Traffic Engineers that a standard be developed for this situation. Further concern has been shown by members of the Traffic Signal Committee of the National Joint Committee on Uniform Traffic Control Devices, who noted the present inconsistency in the use of signals for controlling separate turning movements and offered several suggestions for improving the situation. However, the majority of the suggested solutions appear to be based on the personal experiences of the committee members rather than on any verified research.

In brief, the problem is as follows: There is no uniform treatment of clearance interval indications at intersections where a through phase (no turns) follows a phase

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when turns are permitted, and separate signal faces cannot be provided for the approaches.

PRESENT PRACTICE QUESTIONNAIRE

A total of 1,302 questionnaires were sent to traffic engineers throughout the United States and Canada. Of these, 20 percent were completed and returned. To analyze the data, we classified the questionnaires into 11 methods of left-turn signal indications. Five geographical regions were also established in an effort to determine what methods, if any, might be of a regional nature. Figure 1 shows the left-turn signal indications and phasing for each of the following 11 methods.

Method 1 is generally referred to as the exclusive left-turn method and is covered in the Manual regulations. It involves the use of a separate left-turn lane and a separate left-turn signal face consisting of circular red and yellow lenses and a green left-turn arrow lens. This type of arrangement is usually found at channelized intersections. Separate phases are usually provided for in this situation, and left turns may be made from both approaches simultaneously.

Method 2 is a leading left-turn split-phase signal indication. It involves the use of a signal face consisting of circular red, yellow, and green lenses and a green left-turn arrow lens. This signal face is used by both through traffic and left-turning traffic both using the same traffic lane. This arrangement is generally found at unchannelized intersections.

Method 3 is essentially the same as method 2 except in this case the type of intersection and the location of the signal are different. This method is also a leading left-turn split-phase indication. It involves the use of a separate signal face for left-turning traffic and is usually used in conjunction with a separate left-turn lane.

Method 4 is also a leading left-turn split-phase indication. It generally involves the use of a signal face consisting of red, yellow, and green lenses and a green left-turn arrow lens. The clearance interval for the termination of the protected left-turn movement is indicated by the disappearance of the left-turn arrow leaving only the red indication.

Method 5 is also a leading left-turn split-phase indication. It generally involves the use of a signal face consisting of circular red, yellow, and green lenses. The signal face controlling left-turning traffic may be a separate one or one that is used jointly by left-turning and through traffic. For the most part, however, this type of arrangement is used at channelized intersections with separate left-turn lanes.

Methods 6 and 7 have a lagging left-turn phase. In contrast to a leading left-turn phase, these sequences of indicating a protected left-turn movement take place at the end of the interval provided for the through traffic on the same approach as the left-turning traffic. They generally involve use of circular red and yellow and sometimes green lenses and a green left-turn arrow lens. The signal face controlling the left-turn movement may or may not be used by the through traffic.

Method 8 is a leading split-phase left-turn indication. The results of the questionnaire indicated that, with but one exception, its use is primarily limited to Canada. It involves the use of a signal face consisting of circular red, yellow, and green lenses and a green left-turn arrow lens. For the cases reported it has primarily been used at intersections where through traffic and left-turning traffic use the same lane.

Method 9 is also a leading split-phase operation. The method involves the use of a separate lane and separate signal face to control the movement of left-turning vehicles. The signal face consists of circular red, yellow, and green lenses and an additional green left-turn arrow lens.

Method 10 is also a leading left-turn split-phase indication. However, this method differs from the ones previously described in that permissive turns are not allowed. This is accomplished by the use of a vertical arrow lens for through traffic movement. With this method, through and left-turning traffic use the same traffic lane and signal face.

Method 11 is also a leading split-phase indication. In this arrangement, through and left-turning traffic utilize the same traffic lane and signal face. The signal face consists of circular red, yellow, and green lenses together with yellow and green left-turn lenses placed below the above-mentioned lenses.

Summary

Thirty-three percent of the respondents reported using left-turn signalization method 1, 20.4 percent method 2, and 13.1 percent method 3. Methods 4 and 6 accounted for 8 and 9 percent respectively of the replies. The remainder of the replies were almost evenly divided among all the other left-turn methods.

Analysis of the replies on a regional basis, according to the 11 left-turning methods, indicates the following trends in their usage. The northeastern region reported the highest use of method 1 with the western region next. California was the chief user of this method. Method 2 seemed to be used exclusively in the northeastern, southern, and central regions.

Method 3 was found to be most prevalent in the southern region; however, with the exception of Canada, all other regions reported some limited use of this method. Method 4 is predominantly used in the central region. Method 5 is used exclusively in Canada, particularly in the northeastern provinces. Methods 6 and 7 are most used in the northeastern and southern regions, with the southern region reporting the greatest usage of these methods.

With the exception of Philadelphia, use of method 8 is limited exclusively to Canada, most of the installations being in the western provinces. Methods 9, 10, and 11 were used in all regions except Canada.

Discussion of Questionnaire Replies

It may be concluded from the questionnaires that a variety of left-turn signal indications are being used across the country. Although the analysis indicated certain general trends in the use of the various methods, it may also be concluded that the differences are by no means restricted to the limits of the established geographical regions. Within a single state, as many as five methods may be found in use.

The analysis also shows that at the present time the decision to install a particular left-turn method is often not greatly influenced by the Manual. Different agencies place different emphasis on safety, efficiency, uniformity, and economy. The result is that each agency seeks a method that best fits its individual needs, and the general tendency is for each agency to say that its signal indication method performs satisfactorily.

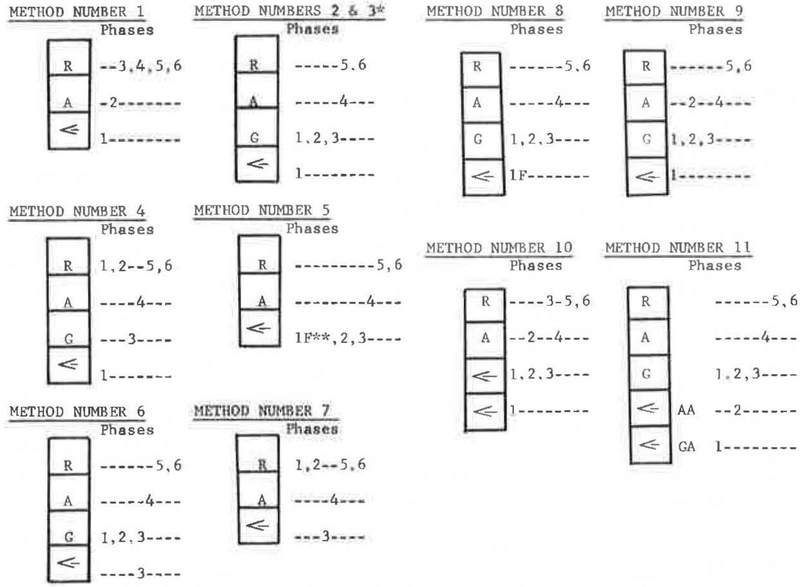
LABORATORY STUDY

The laboratory study was an in-depth investigation of the clearance interval indications at intersections where a through phase (no turns) follows a phase when turns are permitted and separate signal faces cannot be provided for each of the approach lanes. The purpose was to determine what type of signal indication, shown to the left-turning traffic, would best convey to the driver that (a) he may make a left turn, (b) the left turn is about to terminate, and (c) he must yield to opposing traffic. The final product of this portion of the study was a list of several sequences of signal indications that proved to be superior in achieving these three objectives. The basis for evaluation was provided by an information processing model.

Method

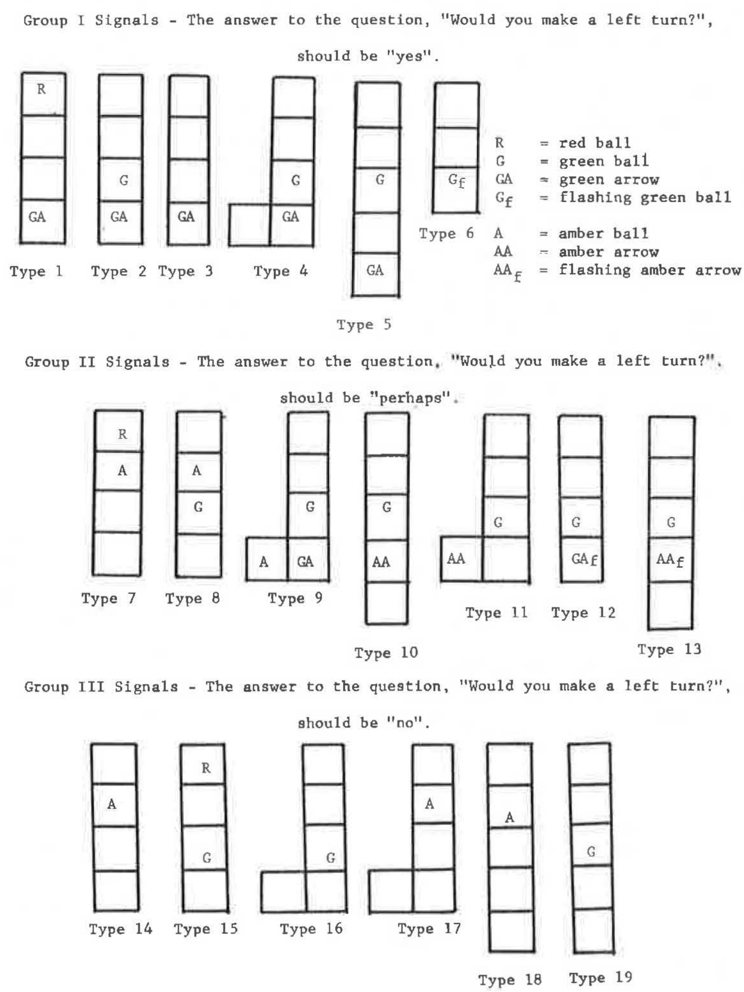
Subjects—A total of 49 male and female subjects were used in the experiment. These subjects were divided into two groups. The main study group consisted of 40 persons whose ages ranged from 18 to 30 and whose driving experience ranged from 0 to 13 years. The second group contained older drivers for the purpose of comparing their understanding of protected left-turn signals with that of the main study group. This group varied in age from 31 to 64 years, and their driving experience ranged from 15 to 44 years.

Figure 1. Methods of left-turn signal indication.



* Difference is the location of the signal faces and the type of intersection.
** F indicates flashing signal phase.

Figure 2. Signal configurations.



The subjects included students and staff of West Virginia University and housewives. The total 49 subjects had some significant driving experience in 16 states and the District of Columbia.

Stimulus Material—Nineteen left-turn signal indications in 14 signal sequences were used in this experiment. These were selected based on the results of the present practice questionnaire and the researcher's judgments. Figure 2 shows the 19 types of signal indications.

The subject's total stimulus contained three sections that were presented simultaneously on two movie screens. The first part of the stimulus was a 35-mm color slide of an intersection, which presented the subject with a visual reference on the type and layout of the intersection he was attempting to maneuver through. The second part of the stimulus was the question, "Would you make a left turn?" The first and second parts of the stimulus remained constant during the entire study period. The final portion of the stimulus consisted of a traffic signal indication, which was the changing portion of the stimulus, and was presented by a 35-mm color slide or Super 8-mm color film for the flashing indications. With each change of signal indication, the subject was to answer the question "Would you make a left turn?" by depressing one of three response buttons, yes, perhaps, and no. The signal indications were divided into group I signals (yes answer), group II signals (perhaps answer), and group III signals (no answer) based on the meanings that practicing traffic engineers intended the signals to convey to drivers.

Procedure—In designing the experimental procedure for this study, the information processing concept of the human operator was employed. The information processing model has provided the fundamentals to much of our present understanding of the factors determining speed and accuracy of human performance. Because statistical evaluation of this laboratory investigation depended on the measures of reaction time and accuracy, it was considered appropriate to apply this proven concept.

After completing a color discrimination and visual acuity test, the subjects were seated before the projection screens. The experimenter then briefly described the purpose of the study, gave instructions to the subjects, and answered questions concerning the subjects' participation. Following a short practice period, the main study period began, during which the subjects' reaction times and accuracies were recorded for each signal presentation.

The investigation was conducted in two parts. Part one tested the response of the subjects to individual signal indications, and in part two the subjects viewed an entire signal sequence or cycle that contained four or five signal indications and responded to these.

For the final portion of the experiment, the subjects were asked to complete a questionnaire that included their personal opinions regarding the signal indications they understood best.

Results

The results indicate a difference in the ability of the signal indications tested to convey a given message to the subject participating in the experiment. The following results were verified by application of the analysis of variance (ANOVA) and the comparison of statistical differences. (Results of the ANOVA are given in Table 1.)

1. The four-signal-head configurations used in the laboratory study did not influence the accuracy or the reaction time of the subjects. An example of this was the green arrow indication, which was easily and correctly understood regardless of its position or accompanying signals.
2. The solid red stop signal had a high degree of population expectancy, which means that the driving public has established a habit or clear logical relationship between the stimulus (red signal) and the response (stop). This was confirmed by part two of the research in which the red light obtained a near perfect accuracy (one miss out of 560 responses) and a low reaction time.
3. None of the three flashing signals tested in the experiment proved to be effective inasmuch as their meanings were not comprehended by the subjects so readily as the competing nonflashing indications.

4. The zone of uncertainty was greatest for the signal indications in group II (perhaps), which shows that the concept of the clearance interval is the most difficult for the subjects to understand.

5. After parts one and two of the experiment had been evaluated, it was concluded that sequences 7, 12, and 13, shown in Figure 3, should be field tested along with sequence cycle 2, which was not tested here because it uses a time offset to accomplish the equivalent of the clearance interval.

6. The data collected from the older study group supported the finding of the main study group. This suggests that age differences do not affect the meaning conveyed by the signal indications.

Discussion of Laboratory Study

The main objective of the laboratory investigation was accomplished in that the number of signal sequences to be field tested was reduced from 14 to three. The argument could be posed that all the signal sequences should be field tested. However, this was not practical because money and manpower were limited. Also it would require a minimum period of 14 months to field test the signal sequences, which would mean working through several different seasons of the year.

The results of this laboratory investigation needed to be field tested to determine whether field differences exist between the signal sequences inasmuch as the subjects in the laboratory were required to perform only one task with no outside distractions. The actual driving task is not so simple because many distractions may be present, particularly when the driver is approaching a busy intersection.

FIELD STUDY

The purpose of the field study was to evaluate the effectiveness of the four left-turn signal indication sequences (Fig. 3), recommended in the laboratory study, under actual operating conditions. The field test was designed to investigate driver response to different signal indication sequences during a protected left turn. A study of the driver's response to the display of the signal indication would explain, within certain limitations, whether the intended meaning of the signal was conveyed and fully understood. On the basis of field observations, it was possible to rate the signal indication sequences according to accuracy of response by the driver, time of driver response, use and misuse of lanes, driver hesitation, number of signal violations, apparent indecision of the driver, and conflicts that occurred during the investigation.

Method

The intersection of Patteson Drive and University Avenue (Fig. 4) was chosen as the study location for the following reasons:

1. Proximity to West Virginia University,
2. Geometric configuration,
3. High percentage of local, repeat users, and
4. Fluctuating traffic volumes throughout the day.

Magnetic loop vehicle detectors were embedded in the roadway, their existence concealed from passing motorists. The detectors were actuated by left-turning vehicles as each approached the intersection and exited from the intersection and by vehicles proceeding through the intersection in either direction. The response of the detectors and the traffic signal phasing were recorded on a constant-speed strip chart recorder. This established a timetable of activity for the study area. Times were recorded for individual vehicle movements.

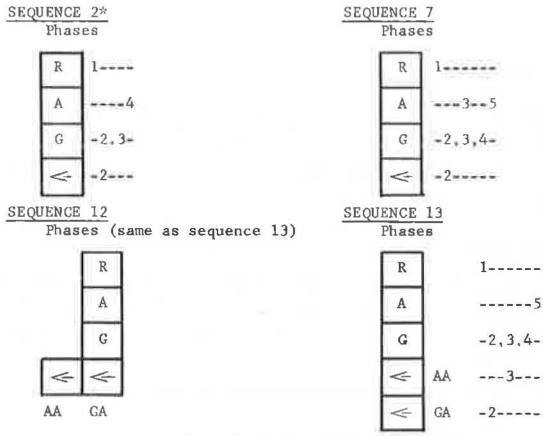
An observer was on duty during each data collection period. From a concealed vantage point, his view of the traffic was unobscured. The observer noted any unusual traffic movements, potential accident situations, and the like. He made a note of the situation and by remote control activated an event marker on the chart recorder to indicate when the situation occurred.

Table 1. Calculated F-ratio from ANOVA tables.

Comparison	Accuracy			Reaction Time		
	Group I	Group II	Group III	Group I	Group II	Group III
Mean squares for subjects versus experimental error	10.141	55.866	21.825	10.798	24.968	25.943
Mean squares for signal indications versus experimental error	1,059.38	256.89	31.99	113.60	20.22	24.00
Mean squares for interaction term versus experimental error	6.384	11.946	3.819	1.638	1.549	1.109[a]

[a]No significant difference; for all others there was significant difference.

Figure 3. Signal sequences tested in field study.

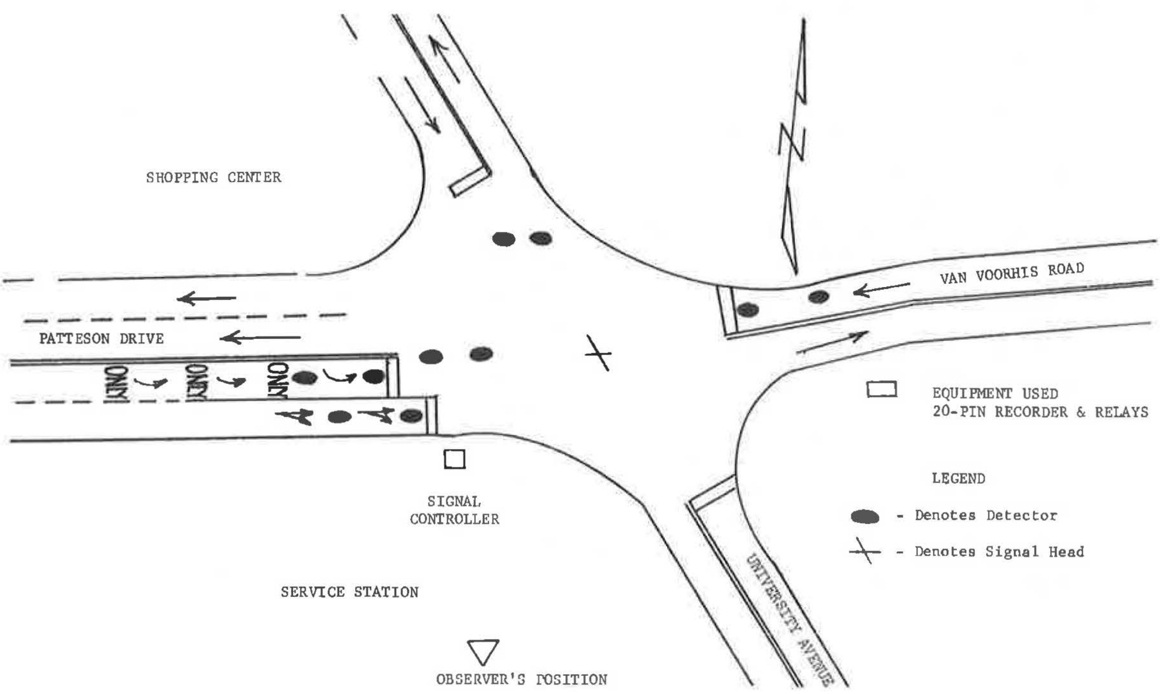


Length of Signal Presentations (in seconds)

Phases	1	2	3	4	5	Total
Sequence 2	36.4	7.0	23.4	3.2		70.0
Sequences 7, 12, 13	36.4	7.0	3.2	20.2	3.2	70.0

* Uses a time delay for the opposing traffic's green phase to accomplish the equivalent of the clearance interval.

Figure 4. Field study intersection.



The signal indication sequences were presented in random order. Following the installation of each sequence, a 7-day adjustment period was allowed for the traffic to become familiar with the new condition. The data collection phase then began and covered the next 2-week period.

To determine the driver's understanding of the different traffic signal indication sequences, we recorded the following data:

1. The starting-up times of left-turning, through, and right-turning vehicles entering the intersection at the start of left-turn indication;
2. The termination of each indication phase in the four signal sequences;
3. The start of each indication phase for the four signal sequences; and
4. The time interval between the termination of the left-turn movement and the start of the opposing through movement.

In addition to this, the starting-up times for the opposing through movement (westbound) were recorded. For the purpose of this study, starting-up time for eastbound traffic is defined as the time interval between the start of the left-turn and green ball signal indication and the beginning of the first queued vehicle at the intersection. The starting-up time for westbound traffic began with the start of the green ball signal indication and ended with the movement of the first vehicle.

Environmental factors affecting driver performance at the study area were also considered. Data were collected only on those days that had ideal weather conditions. On rainy days, when the road was wet, or when visiblity was poor due to heavy fog, no data were collected. All data collection at the intersection was done during daylight hours.

Following these considerations, the field study was conducted to determine which signal indication sequence best conveyed its intended message to the driver. The following equipment, the location of which is shown in Figure 4, was used to record the data:

1. Magnetic loop vehicle detectors,
2. Marblelite traffic signals,
3. Amplifiers and radio receiving equipment,
4. Esterline Angus 20-pen inklers recorder, and
5. Signal control box.

With this equipment it was possible to record the start of each signal phase, the starting-up times of the first vehicles in the left- and right-turning lanes, road violations made by the motorists, number of cars passing through the intersection during the study periods, and times at which left-turn vehicles started their movement (entered the conflict area) and completed their movement (cleared the conflict area). The starting-up times of the opposing through traffic and the times when the vehicles entered the intersection were also recorded.

Results

To analyze the data collected in the field study required that, first, the data be converted from the 20-pen recorder tape to a more convenient form. This was accomplished by designating the start of each green arrow indication as the zero time base and recording the time for vehicular events with respect to this datum. The data were transferred to prepared forms and then punched into computer cards for processing. Data were analyzed both graphically and statistically.

Data were tabulated to show the number of vehicles entering the intersection after the start of the green arrow indication for each signal sequence. Included were all vehicles entering the intersection after the start of the green arrow until the time when the green arrow went out and left-turning vehicles began to yield the right-of-way to the opposing through traffic movement. The utilization of the left-turn interval also shows the extent to which drivers are preempting the right-of-way from the opposing through traffic movements. Inspection of the data shows that left-turning drivers tended to yield the right-of-way more often with signal indications 12 and 13 than with signal indications 2 and 7.

Vehicle starting-up times were extracted from the data. These starting-up times indicate the extent of driver perception of the left-turn signal display. The starting-up times would indicate whether the meaning of the signal display was understood by the motorist. The starting-up times for the first vehicle and the second vehicle in the left-turn lane were subjected to an ANOVA. The results of these tests are given in Table 2. Both showed significance at the 5 percent level. This meant that differences in starting-up times did exist between the types of signal sequences. Inspection of Figure 5 shows that signal sequences 12 and 13 have lower starting-up times for first and second vehicles than signal sequences 2 and 7.

An ANOVA was also performed using the starting-up time data from the through or right-turn lane vehicles. These data proved statistically significant for both the first and second vehicles. This showed that a difference exists in the ability of the four signal sequences to encourage quicker starting times. Bar graphs (Fig. 5) show that signal sequences 12 and 13 have shorter starting-up times.

The conclusion drawn from these tests was that the starting-up times for left-turning and right-turning and through vehicles were significantly longer for signal indications 2 and 7 than for signal indications 12 and 13. However, there is no significant difference between the mean starting-up times for signal indications 12 and 13.

A comparison of the total time required for a left-turning vehicle to travel through the intersection was conducted. The results are shown in Figure 5. This time was measured from the point the car entered the intersection until its rear bumper exited the conflict area. The results of the ANOVA given in Table 3 show that statistically significant differences exist among the signal sequences. Analysis of the mean times shows that signal sequences 2 and 7 have longer times than sequences 12 and 13.

The establishment of the critical difference was based on the length of time that would be required for a vehicle to clear a 12-ft lane at an average speed of approximately 24 fps. It was postulated that a vehicle starting ½ sec later than normal would allow one vehicle less to clear the intersection during each signal cycle. The result of this would be a reduction in the capacity of the intersection. The lower starting-up time test results indicate that motorists understood the displays of signal sequences 12 and 13 better than signal sequences 2 and 7. Furthermore, the results also indicate that the efficiency of the intersection was increased when signal sequences 12 and 13 were employed.

For the purpose of this investigation, a violation was defined as the movement of a vehicle into the conflict area after the start of the left-turn clearance interval. Crossing into the conflict area after the start of the clearance interval means that the vehicle could be trapped in the intersection and thus interfere with the right-of-way of the opposing through traffic. The investigation showed that the resulting preempting was more likely to occur at times when the ratio of opposing through traffic to left-turn traffic was low. This general trend was observed during the testing of all four traffic signal indications. A greater number of violations were recorded for sequences 2 and 7 than for sequences 12 and 13.

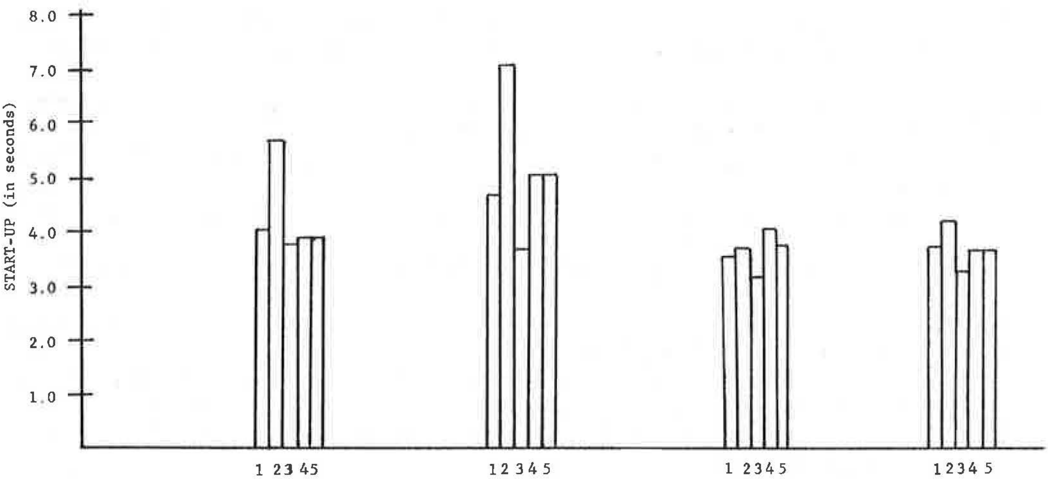
The results can be briefly summarized as follows:

1. Signal indication sequences 12 and 13 proved superior in conveying the message that the driver had a protected left turn, that the protected left turn was about to terminate, and that the driver did not have a protected left turn;
2. Sequences 12 and 13 encouraged left-turning motorists to yield the right-of-way more often than sequences 2 and 7;
3. The starting-up times for left-turn and right or through vehicle movements were lower for signal sequences 12 and 13 than for sequences 2 and 7;
4. Signal indication sequence 7 proved to be the most ineffective of the four sequences tested, for there was evidence of driver hesitation in both approach lanes during the third indication phase of this signal;
5. Fewer traffic flow violations resulted with sequences 12 and 13 than with sequences 2 and 7; and
6. Speeds of left-turning vehicles were affected by the signal indication sequence, and driver left-turning speeds were higher with signal sequences 12 and 13.

Table 2. Statistical analysis of starting-up times.

Vehicle Position	Lane	Source	df	SS	MS	F
1	Left	Signal sequences	3	33.264	11.088	7.921
		Residual	165	230.969	1.399	
		Total	168	264.233		
2	Left	Signal sequences	3	42.299	14.099	21.255
		Residual	20	13.267	0.633	
		Total	23	55.566		
1	Right or through	Signal sequences	3	19.637	6.546	6.717
		Residual	336	327.443	0.975	
		Total	339	347.080		
2	Right or through	Signal sequences	3	85.705	28.568	37.643
		Residual	226	171.516	0.759	
		Total	229	257.221		

Figure 5. Average starting-up times.



1-first vehicle in queue turning left from Patteson Drive; 2-second vehicle in queue turning left from Patteson Drive; 3-first vehicle in queue proceeding straight through intersection; 4-second vehicle in queue proceeding straight through intersection; 5-time required for vehicle to make complete left turn movement (time spent in conflict area).

Table 3. Statistical analysis of total time left-turning vehicle spent in intersection.

Source	df	SS	MS	F
Signal sequences	3	33.182	11.061	6.175[a]
Residual	212	380.868	1.797	
Total	215	414.050		

[a]$p < 0.05$.

Discussion of Field Study

The field study results show signal sequences 12 and 13 to be superior to sequences 2 and 7 in their ability to convey the intended message to the driver. The field test showed no significant difference between sequences 12 and 13. However, this was not totally unexpected inasmuch as the only difference between the two was the physical arrangement of the five faces. Fewer traffic violations were noted for sequences 12 and 13, and starting-up times were reduced over those of sequences 2 and 7. Sequence 7 proved to be the least effective in that it seemed to encourage driver hesitation during the amber interval.

Based on ease of installation and driver expectation, it is further recommended that signal sequence 13 be given preference over sequence 12.

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