AN ASSESSMENT OF EXCLUSIVE/PERMISSIVE LEFT-TURN SIGNAL PHASING

by

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(The opinions, findings, and conclusions expressed in this report are those of the author and not necessarily those of the sponsoring agencies.)

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SUMMARY AND CONCLUSIONS

The study has shown that more than one-third of the questioned motorists were confused by exclusive permissive (E/P) signals the first time they encountered them, but that this confusion dissipated as they became familiar with the signal. At every test site, motorist confusion was found to decrease over time. Although driver confusion obviously can be attributable to other factors in the case of E/P signal indications, it is safe to say that familiarity with the installation reduces confusion. It thus appears that driver confusion with a new E/P installation or modification might be further reduced through some sort of advance publicity. A sign placed adjacent to the E/P signal was also found to aid in the reduction of motorist confusion, as more than 90% of the respondents in the survey believed such a sign to be helpful.

Slightly more than 70% of those returning questionnaires were in favor of E/P signals, and only about 17% said the signal should not be used. Moreover, 77% felt that the E/P signal phasing had reduced delays at the intersections. On the other hand, slightly more than 30% felt that the E/P installations created a hazardous situation. The data did show, however, that motorists who had had previous experience with this kind of signal tended to be more positive about it than did those without such experience. The implications again are that familiarity with the E/P signal tends to reduce apprehension about it and that advance publicity or public information has merit. Furthermore, when asked what kind of advance publicity was desirable only about 18% said none. The newspaper was seen as being the most effective type of publicity, while a mailed flyer ran a close second.

Vehicular conflicts at E/P signals were most frequent at intersections with high volumes of left-turning traffic and multiple movements. While intersections with one or more right-turn-on-red movements seemed especially susceptible to motorist conflicts, the conflict rate could not be attributed to any one characteristic of the intersections, but probably was the result of a combination of several. Therefore, the effect of the E/P signal on the conflict rate could not be ascertained. There is some evidence that the modification of existing signals may result in a slightly higher conflict rate than will the installation of a new signal, but the data in support of this conclusion are sketchy at best. The same is true for accident rates at these intersections. At best, all that can be said about accidents based upon the data gathered in this study is that the ratios of accidents involving left-turning vehicles to all accidents occurring at the intersections appeared to increase after the E/P signal was installed.

RECOMMENDATIONS

The findings from the study have led to the following recommendations.

1. In order to establish firm guidelines for the installation of E/P left-turn phasing at new locations and for modifying existing locations, an evaluation should be conducted to compare existing E/P locations to non-E/P intersections on the basis of such characteristics as approach and left-turn traffic volumes, traffic mix, speed limit, geometrics, sight distance, accident rate, conflict rate, intersection configuration, commercial development, and location (urban or rural).

2. Since the public generally appears to favor the use of E/P left-turn phasing, the use of this type of signal should be considered at all new left-turn phasing locations. Such consideration should take into account the findings from the study proposed in recommendation #1, if the study is conducted.

3. A supplemental exclusive regulatory traffic signal sign such as the one shown in Appendix C of this report should always be used. At least one such sign shall be adjacent to the signal head controlling the left-turn movement.

4. The supplemental sign cited in recommendation #3 should be included in Section 2B-37 of the MUTCD.

5. Advance publicity should precede the installation of E/P signals. Specifically, a statewide public information campaign in the form of public service announcements by television stations or newspapers should be undertaken to make motorists in Virginia aware of the increased use of this type of signal phasing. Such a compaign might be similar to that conducted for the right-turn-on-red maneuver. When existing signals are modified to include E/P phasing residents of the area should be notified, preferably with a mailed pamphlet.

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INTRODUCTION

In Virginia, several means are used to accommodate left-turn movements at signalized intersections. At many locations, the left turns must be made on a green signal indication after the motorist yields to opposing traffic. Where there is a large volume of left-turning traffic, an exclusive left-turn phase is provided to permit left turns only during the green-arrow phase, when all opposing vehicular traffic is stopped. In the recently introduced exclusive/permissive (E/P) left-turn signal phase, the left turns are permitted during the display of both the green arrow and the green ball. During the green-arrow phase, the left-turning motorist is unopposed, while during the green-ball phase he must yield to opposing vehicular traffic. The left-turn arrow may either follow or precede the green ball. Nationwide, several studies have been conducted to determine the best method for signalizing left-turn movements and as many as two dozen various signal indications are available for use. A recent study of E/P left-turn phasing determined that the frequency of its use varied substantially within various agencies.(1) There was general agreement that E/P phasing is efficient because it results in fewer delays than other types of left-turn phasing. However, it was found to also lead to an increase in accidents compared to exclusive phasing. A later study determined, for example, that E/P left-turn phasing resulted in a 50% reduction in left-turn delay and a 24% reduction in total delay compared to exclusive phasing.(2) There was,however, a marked increase in accidents involving left-turning vehicles that decreased over time. In a questionnaire survey, over 90% of the drivers responding were in favor of this type of signal. Some had not understood the signal the first time they had gone through the intersection, and they indicated that more advance publicity on the E/P signal was necessary.

The Department has numerous E/P signal-phasing installations throughout Virginia. To date, public reaction to this type of phasing has been favorable, except where accidents have occurred.

Department data show that there usually is a high incidence of minor accidents immediately after the installations are made but that the number of accidents declines over time. These data seem to suggest that advance publicity on all installations of this type may be desirable. While it is the intent of the Department to increase its use of the E/P left-turn signal, an examination of the public's reaction to it was needed.

PURPOSE AND SCOPE

The purpose of this study was to assess the performance of E/P left-turn signal phasing in Virginia. Specifically, the objectives were to —

1. evaluate the effectiveness of in-place E/P left-turn signals,

2. determine the public's attitude toward and understanding of E/P phasing, and

3. determine whether advance publicity on the installation of E/P left-turn signals might decrease conflicts and accident rates.

To obtain the information needed to accomplish these objectives, ten E/P-signalled intersections were chosen for evaluation. Conflicts were observed, accident reports were analyzed, and mailed attitudinal surveys of motorists were taken for each site. The survey was limited to individuals residing within a short radius of the intersections.

METHODOLOGY

Once the ten sites to be evaluated had been chosen, four types of data were gathered for each of the sites. First, traffic counters were installed on the roadway to determine the through traffic volume. Next, on two successive days, observers were placed at opposite ends of the intersection for ten hours to record conflicts. Five types of conflicts were recorded and conflict volumes taken for the two days were averaged, as were the through traffic volumes, which were also taken for two days. To determine the left-turn conflicts, a procedure developed for a previous study was used.[3] Observed conflicts were categorized as follows:

Type 1 — The basic left-turn conflict caused by the turning vehicle crossing in front of or blocking the lane of an opposing through vehicle. A conflict was recorded when the driver of the through vehicle applied his brakes or weaved to evade the encroaching vehicle.

Type 2 — A continuation of the first type in which a second through vehicle following the first one also had to brake.

Type 3 — The conflict caused by the vehicle entering the intersection after the E/P signal had turned red.

Type 4 — The rear-end conflict in the left-turn lane occurring when the driver of the vehicle about to make the turn did not and the driver of the following vehicle had to brake or weave.

Type 5 — The conflict occurring when left-turning vehicles overflowed the storage lane and blocked the through lanes.

In addition, the number of left turns made on the green arrow at each intersection was also recorded.

Once these data were collected, residences and some small businesses located near each E/P intersection were mailed questionnaires asking them to respond to some questions concerning the newly installed E/P signal (Appendices A and B).

Finally, accidents reported at each intersection both before and after the E/P installation was made were tabulated. The after data included accidents reported during the period between the installation date and the date of the on-site evaluation and the before data those reported over a like period of time prior to the installation. In this manner, the impact of the E/P signal on accidents at the intersection were evaluated.

Of the roughly 1,252 questionnaires distributed, 481 were returned for a response rate of 38.4%. However, 21 of these respondents noted that they did not use the intersection and their responses were not included in the data analysis.

RESULTS OF QUESTIONNAIRE SURVEY

Motorist Familiarity With and Confusion at E/P Intersection

The respondents were first asked to estimate the number of times each week they made a left turn at the intersection pictured.

on the questionnaire. The respondents averaged about 8 turns per week, with the greatest number making 11 or more. Only 7.4% of the respondents said they made turns at the intersection fewer than 3 times per week. This information established that those participating in the survey were familiar enough with the signal to answer questions about it.

Table 1 shows the distribution of responses for two questions aimed at determining the degree of confusion caused by the new signal installation. The table shows that more than one-third of the motorists were confused the first time they passed through the intersection, but that only a little more than 12% remained confused. Moreover, as Table 2 shows, motorist confusion relative to the E/P signal was reduced over time at every site. However, the table also shows that the degree to which confusion reduced with time varied among the sites. For instance, the E/P signals at sites 1 and 2 had been in place for about the same length of time, yet for site 1 there was a 100% change in the percentage of motorists who said they were confused with the signal at first, while for site 2 there was only a 40% drop. The situation was similar for sites 9 and 10. These signals had been in place for the same amount of time, yet the responses showed that a great deal more confusion still existed at site 10 than at site 9. Obviously, factors other than unfamiliarity with a new type of signal were responsible for the continuing confusion, as will be made evident later in this report. Such variables as speed limit, through volume, turn volume, intersection configuration, geometrics, sight distance and the like definitely affect a driver's ability to understand the E/P signal indication.

Cross tabulations between the responses to the question on confusion revealed that individuals who were still confused by the E/P signal were found to be more generally negative toward it than were those who were not confused. Also, more often than not, those who were not confused had seen this type of signal elsewhere.

Table 1

Questions Pertaining to Motorist Confusion
(N=460)

QUESTION	PERCENT		
	Yes	No	No Response
Was signal confusing to you the first time you passed through intersection?	36.5	60.7	2.8
Is signal confusing to you now?	12.4	84.6	3.0

Table 2

Change in Motorist Confusion Over Time
(N=460)

Site	Time Since Installation	PERCENT Confused at First	Confused Now	Change
2	2 years	3.6	-0-	100.0
2	2 years	17.2	10.3	40.1
3	17 months	6.5	-0-	100.0
4	16 months	38.3	19.1	50.1
5	1 year	26.2	8.2	68.7
6	1 year	50.0	27.3	45.4
7	9 months	31.8	4.5	85.8
8	7 months	36.5	9.5	74.0
9	5 months	61.5	9.6	84.4
10	5 months	71.4	38.1	46.6

Respondents were overwhelmingly in support of placing a supplementary sign (Appendix C) near the signal to explain that a left-turning vehicle must yield on a green ball. Only 9.3% felt that such a sign was not necessary. Forty percent of the respondents felt that the best placement for such a sign would be adjacent to the signal head. Another 37.6% felt that the signs were necessary both adjacent to the signal head and in the median, where one exits. It should be noted here that five of the E/P signals, all located in cities, were not signed. For the surveys made at these five locations, 67.8% of the respondents felt a sign was necessary adjacent to the signal head, in the median, or both. For the five sites that included a supplementary sign, this opinion was held by 86.6%. Since all but one of the E/P signals not accompanied by the sign continue to confuse motorists, perhaps the addition of the sign might reduce confusion. One of these four intersections has been particularly plagued by accidents, which may be due in part to driver confusion as to what the E/P signal means. The addition of a sign would likely reduce the accident rate there.

General Opinion and Impact of E/P Signal on Intersections

Each respondent was asked to give his overall opinion of the E/P turn signal. Slightly more than 70% were in favor of this type of signal, about 11% were neutral, and about 17% were against it. It should be noted also that at E/P signalled intersections

where the conflict and accident rates were high, public opinion generally was more negative than it was at less conflict and accident prone intersections.

Table 3 shows a summary of responses to questions concerning the impact of the E/P signal on the intersection. Overall, 77.0% of the respondents felt that E/P signal phasing had reduced delay at the intersections evaluated. However, about 30.0% felt that a hazardous situation existed at the intersections because of the E/P signal and, in fact, roughly 21.0% indicated that they had been involved in a crash or near miss at one of the E/P intersections. Cross tabulations revealed the existence of some interesting relationships between the answers to these questions and to certain other variables. As would be expected, respondents who had a positive opinion about the E/P signal felt it had had a positive effect on the intersection — that is, it had reduced delays and had not created a hazard. It was also found that individuals who had seen this type of signal in other areas were more likely to feel the signal had had a positive effect on the intersection than those who had not. Both this and the preceding relationship were significant at the 99% level of confidence. The implication here is again that familiarity with the E/P treatment tends to reduce apprehension about it. Furthermore, cross tabulations showed that individuals who had seen the E/P signal in other areas were less likely to have ever been involved in a crash or near miss at the intersection. This relationship was significant at the 95% level of confidence and exhibits the probability that advance familiarity with the E/P signal treatment might reduce vehicle conflict and accident rates.

Table 3

Summary of Responses Regarding Intersection Inpacts of E/P Signal (N=460)

QUESTION	PERCENT RESPONDING		
	Yes	No	No Response
Has signal reduced delays?	77.0	19.3	3.7
Has signal created a hazard?	30.5	65.4	4.1
Have you been involved in a crash or near miss?	20.9	78.0	1.1

Advance Publicity: Will It Reduce Intersection Confusion?

Much of the preceding points to the fact that familiarity with the E/P signal is an aid to the motorist. To take this concept one step further would be to suggest that advance publicity on E/P installations would be of even more help. While this suggestion is embodied in responses to previous questionnaire items, it is strengthened by responses to a question regarding the type of advance publicity that might be helpful. More than 82% of the respondents related that they had known nothing of the E/P signal change until after it had been installed and they had entered the intersection. Table 4 shows the types of publicity respondents felt would benefit them most. The reader will remember that roughly 36% of the respondents had been confused by the E/P signal the first time they encountered it.

As can be seen, only 17.6% of the respondents felt no advance publicity was necessary. As was expected, the newspaper was felt to be the most effective method for publicity of this type, while 34% of the respondents preferred a mailer. This preference, then, indicates that should a public information campaign be launched to inform the motorist that an E/P signal is being installed, a mailed flyer, along with newspaper coverage, should be used. Radio and television coverage are not as desirable and only minimal use should be made of them.

Table 4

Preferred Methods for Advance Publicity
(N=460)

METHOD	PERCENTAGE OF RESPONDENTS*
Newspaper	38.0
Mailers	34.1
None necessary	17.6
Radio	17.4
TV	14.3
Miscellaneous	9.6

*Percentages do not total 100 due to multiple responses.

Respondents' Comments

Space was provided at the end of the questionnaire for comments or suggestions concerning the E/P signal. Of the 490 people responding to the questionnaire, 347, or more than 75%, entered comments or suggestions. These comments, shown by category in Table 5, provided a wealth of information and some interesting suggestions for consideration by those responsible for the selection of sites for E/P installations. These comments can be further reduced to four categories: (1) negative remarks, 48.7%; (2) positive remarks, 23.6%; (3) suggestions, 13.3%; and (4) miscellaneous remarks, 14.4%. Item 1 in Table 5 was classified as a positive remark, items 2, 3, 4, and 6 as negative remarks, items 5, 7, and 8 as suggestions, and item 9 as miscellaneous. These are discussed in the succeeding paragraphs.

Table 5

Frequency of Motorist Comments
(N=374)

	CATEGORY	NUMBER	PERCENT
1.	Should increase use of E/P treatments	82	23.6
2.	Has hazardous effect on intersection	72	20.8
3.	Drivers misinterpret signal	56	16.1
4.	Characteristics of intersection not conducive to E/P signal	22	6.3
5.	Advance publicity needed	20	5.8
6.	Against E/P concept; protected phase only	19	5.5
7.	Signal design suggestions	17	4.9
8.	Sign design suggestions	9	2.6
9.	Miscellaneous	50	14.4
	TOTAL	347	100.0

Should Increase Use of E/P Treatments

These comments were considered positive in that they supported the use of the E/P signal and these respondents called for the Department to install E/P signals at additional intersections in their areas. Many remarked that the E/P signal definitely improved traffic flow and thus reduced delay, while a few said the signal

saved gas. Much of the positive support was found in the more rural, less congested areas. In fact, the less congested the intersection, the more positive was the comment.

Hazardous Effect on Intersection

These comments, obviously negative, noted several types of hazardous behavior brought about by the E/P signal. Many of these comments alluded to the fact that drivers took too many chances on the green ball. This was especially true at busy intersections where drivers always seemed to be "in a hurry." Also noted as being problematic was the tendency for stacking lanes to become full and often to overflow and cause congestion in the remaining lanes. These two problems were also discovered by on-site observers and will be further discussed later. Motorists also noted that at several intersections, sight distance of the opposing lanes was limited by trees, shrubs, and signs, and by vehicles in the stacking lane, thus resulting in an unsafe situation when the signal was in the permissive phase.

Drivers Misinterpret Signal

These comments were also negative but differed slightly from those noted in the previous section. These comments related to the manner in which motorists responded to the signal. The biggest complaint was that drivers created "traffic jams" by moving into an intersection under the exclusive arrow, remaining in the opposing lanes during the permissive phase, and thus blocking traffic in the opposing lanes. Also cited were the instances where motorists turning on the permissive green ball at four-way intersections moved into the crossover to wait for a gap in the opposing traffic, and were "trapped" in the crossover when the signal for the traffic entering the intersection from the minor street turned green. This traffic also attempted to move into the crossover. One can easily imagine the confusion that results from these traffic movements at a four-way intersection.

Characteristics of Intersection Not Conducive to E/P Treatment

These comments, mostly negative, might have been grouped with the ones in the preceding section, except that the author wanted to impart some specific suggestions made by motorists. Of these 22 comments, 7 were that the stacking lane needed to be lengthened. This potential cause of conflict was also noted by the observers

recording conflicts. Five comments in this category were that the speed limit on the major road was too high for an E/P signal to be used, and another 2 comments referred to the interference between vehicular and pedestrian traffic at some E/P signals. Observers did not notice such interference at any of the ten study sites. One of the most interesting comments in this category had to do with the interference between motorists turning left on the exclusive arrow onto a major street and those making a right-turn-on-red from an opposing minor street onto the major street. Observers noted time and again that this was a problem, as was the allowing of U-turns at E/P intersections. It appears that allowing these two types of movements at E/P intersections needs to be given a hard look.

Advance Publicity Needed

Twenty of the respondents said they felt that advance publicity might alleviate driver confusion at E/P intersections. Several of these respondents explained that the intersection was confusing at first, and that over time the confusion seemed to subside. This comment tends to support cross tabulations of data presented earlier which showed that familiarity with the E/P signal is an aid to motorists.

Against E/P Signal at This Intersection

These respondents were not necessarily negative on the entire E/P issue, but were not in favor of the signal being used at their particular intersections. Nine of these comments suggested that the protected phase only should be used. These comments were scattered through the ten sites and were not significant for any one site.

Sign/Signal Design Suggestions

These comments, while representing only 7.5% of those made, pointed out several design items which might be of interest to traffic engineers. Relative to signal design, several respondents pointed out that green has always meant "go" and suggested that the green ball flash or that it be changed to a flashing yellow ball. Relative to sign design, there were suggestions that color blind motorists cannot discern the green color of the ball on the sign. Some respondents also suggested that a yield sign be used on the E/P signal sign in place of the word "yield". Still others merely related that the sign was of great help and that it should be mounted adjacent to the signal when possible.

RESULTS OF INTERSECTION ANALYSIS

This section of the report discusses the characteristics of the ten intersections evaluated to show the variation among the sites. The first section includes a description of the site characteristics of the ten intersections while the second presents a table summarizing the questionnaire responses for each of the ten sites.

Intersection Characteristics

Figures 1 through 10 present photographs and pertinent observed characteristics of the ten E/P intersections studied. The reader will remember that these observations were made over a two-day period, such that the volumes and conflicts presented are averages. The average approach volume at the ten intersections was about 5,800 vehicles, with the highest count being 10,711 vehicles per day and the lowest 3,134 vehicles per day. Since types 1, 2, and 3 conflicts constituted almost 98% of those counted, type 4 and 5 conflicts were not considered problematic and thus will not be discussed. Type 1 conflicts were more frequent at intersections with high volumes of turning traffic. Three of the four intersections with the highest such volumes (green arrow and green ball) also had the highest rate of type 1 conflicts. Type 2 conflicts were generally rare (about 4.6 per day per intersection), and while most of these conflicts tended to occur at intersections having the highest turn volumes, such was not the situation in every case. In fact, conflict rates could not be attributed specifically to any one characteristic of an intersection such as approach or turn volumes (green ball or green arrow). Type 3 conflicts were more dominant than either of the previous two types, but instances of high type 3 conflicts could not be attributed to any one characteristic of an intersection. While these types of conflicts tended to occur at high approach volume intersections in non-shopping-center-oriented areas, it appears that they result more from drivers being in a hurry than from a misunderstanding of the signal indications. At the high volume shopping center intersections type 3 conflicts were relatively infrequent.

Speed limits appeared to have no effect on conflict rates, nor did the length of time that an E/P signal had been in place, up to a year. It did appear that at intersections with high turn volumes an explanatory sign was of importance. One of the intersections with the highest left-turn volumes and no explanatory sign had high ratios of types 1, 3, and 5 conflicts. Moreover, there is evidence that the installation of a new signal containing an E/P phase may result in fewer conflicts at intersections than the modification of an existing signal to one containing an E/P phase.

Figure 1. Site 1. Ivy Rd. — Emmet St., Charlottesville.

Approach volume — 4,434 Speed limit 25 mph (40 kph)
Left-turn volumes: On green ball 172
On green arrow 433
Average daily conflicts: Type 1 - 7.5 Type 2 - 1
Type 3 - 5 Type 4 - 0
Type 5 - 0

Type 1 conflicts by approach volume — 1 per 591 veh.
Type 1 conflicts by left-turn volume — 1 per 22.9 veh.
Type 2 conflicts by approach volume — 1 per 4,434 veh.
Type 2 conflicts by left-turn volume — 1 per 172 veh.
Type 3 conflicts by approach volume — 1 per 1,478 veh.

Figure 2. Site 2. Rte. 29 — Greenbrier Dr. Charlottesville.

Approach Volume — 10,711 Speed limit 45 mph (72 kph)
Left-turn volumes: On green ball 649
On green arrow 977
Average daily conflicts: Type 1 — 122.5 Type 2 - 31
Type 3 — 117.5 Type 4 - 1
Type 5 — 2

Type 1 conflicts by approach volume — 1 per 87.4 veh.
Type 1 conflicts by left-turn volume — 1 per 5.3 veh.
Type 2 conflicts by approach volume — 1 per 345 veh.
Type 2 conflicts by left-turn volume — 1 per 20.9 veh.
Type 3 conflicts by approach volume — 1 per 91.2 veh.

Figure 3. Site 3. University Ave. — Rugby Rd., Charlottesville.

Approach volume — 3,134 Speed limit 25 mph (40 kph)
Left-turn volumes: On green ball — 245
On green arrow — 530
Average daily conflicts: Type 1 - 5 Type 2 - 2
Type 3 - 37.5 Type 4 - 1
Type 5 - 0

Type 1 conflicts by approach volume — 1 per 626 veh.
Type 1 conflicts by left-turn volume — 1 per 49 veh.
Type 2 conflicts by approach volume — 1 per 1,567 veh.
Type 2 conflicts by left-turn volume — 1 per 122 veh.
Type 3 conflicts by approach volume — 1 per 83.6 veh.

Figure 4. Site 4. Rte. 29 - Fashion Square Mall, Charlottesville.

Approach volume — 8,401 Speed limit 45 mph (72 kph)
Left-turn volumes: On green ball — 616
On green arrow — 296
Average daily conflicts: Type 1 - 8.5 Type 2 - .5
Type 3 - 4 Type 4 - 0
Type 5 - 0

Type 1 conflicts by approach volume — 1 per 988 veh.
Type 1 conflicts by left-turn volume — 1 per 72.5 veh.
Type 2 conflicts by approach volume — 1 per 16,802 veh.
Type 2 conflicts by left-turn volume — 1 per 1,232 veh.
Type 3 conflicts by approach volume — 1 per 2,100 veh.

Figure 5. Site 5. Rte. 10 - Rte. 638, Chesterfield County.

Approach volume — 3,255 Speed limit 45 mph (72 kph)
Left-turn volumes: On green ball — 183
On green arrow — 128
Average daily conflicts: Type 1 - 3.5 Type 2 - .5
Type 3 - 2 Type 4 - 0
Type 5 - 0

Type 1 conflicts by approach volume — 1 per 930 veh.
Type 1 conflicts by left-turn volume — 1 per 52.9 veh.
Type 2 conflicts by approach volume — 1 per 6,510 veh.
Type 2 conflicts by left-turn volume — 1 per 366 veh.
Type 3 conflicts by approach volume — 1 per 1,627 veh.

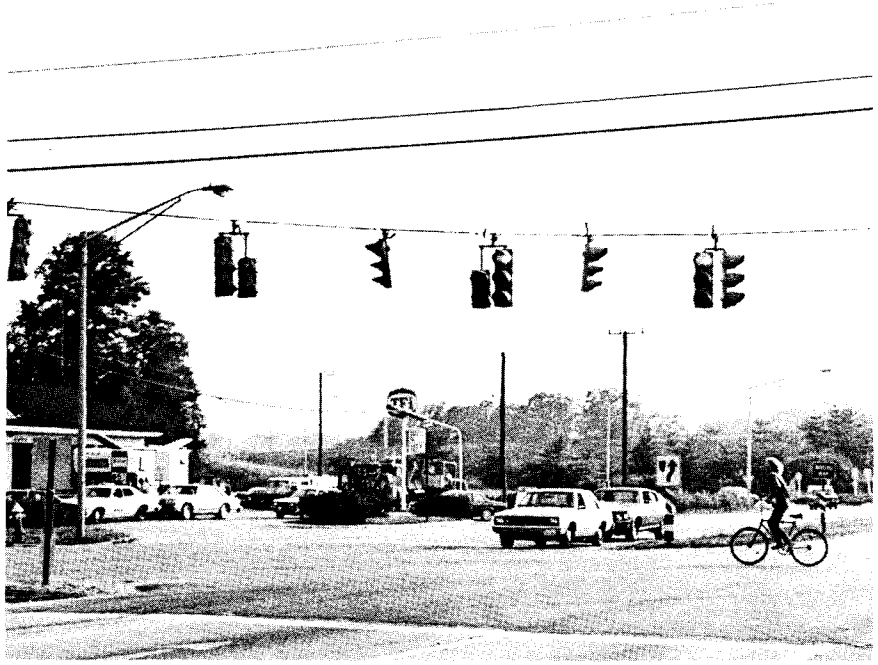

Figure 6. Site 6. Rte. 60 - Greenwell Rd., Virginia Beach.

Approach volume — 6,426 Speed limit 50 mph (80 kph)
Left-turn volumes: On green ball — 117
On green arrow — 35
Average daily conflicts: Type 1 - 4 Type 2 - .5
Type 3 - 7 Type 4 - 0
Type 5 - 0

Type 1 conflicts by approach volume — 1 per 1,606 veh.
Type 1 conflicts by left-turn volume — 1 per 29.2 veh.
Type 2 conflicts by approach volume — 1 per 12,850 veh.
Type 2 conflicts by left-turn volume — 1 per 234 veh.
Type 3 conflicts by approach volume — 1 per 918 veh.

Figure 7. Site. 7. Rte. 11 - Rte. 623, Roanoke.

Approach volume — 3,449 Speed limit — 35 mph (56 kph)
Left-turn volumes: On green ball — 275
On green arrow — 265
Average daily conflicts: Type 1 - 3 Type 2 - .5
Type 3 - 12 Type 4 - 0
Type 5 - 0

Type 1 conflicts by approach volume — 1 per 1,149 veh.
Type 1 conflicts by left-turn volume — 1 per 91.7 veh.
Type 2 conflicts by approach volume — 1 per 6,898 veh.
Type 2 conflicts by left-turn volume — 1 per 550 veh.
Type 3 conflicts by approach volume — 1 per 287 veh.

Figure 8. Site 8. Baxter Rd. and Princess Anne Rd., Virginia Beach.

Approach volume — 5,493 Speed limit 45 mph (72 kph)
Left-turn volumes: On green ball — 721
On green arrow — 813
Average daily conflicts: Type 1 - 9.5 Type 2 - 1
Type 3 - 66.5 Type 4 - 1
Type 5 - 11.5

Type 1 conflicts by approach volume — 1 per 578 veh.
Type 1 conflicts by left-turn volume — 1 per 75.9 veh.
Type 2 conflicts by approach volume — 1 per 5,493 veh.
Type 2 conflicts by left-turn volume — 1 per 721 veh.
Type 3 conflicts by approach volume — 1 per 82.6 veh.

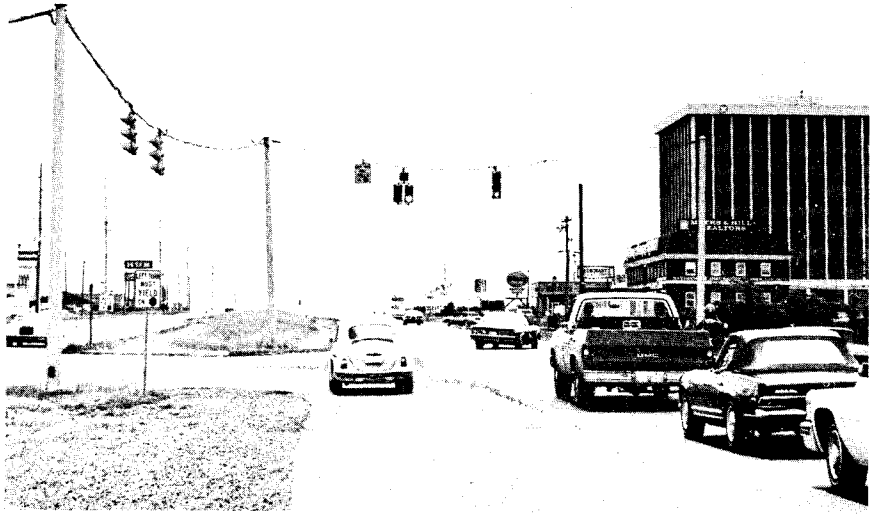

Figure 9. Site 9. Rte. 234 - Rte. 1566, Prince William County.

Approach volume — 4,219 Speed limit 45 mph (72 kph)
Left-turn volumes: On green ball — 547
On green arrow — 860
Average daily conflicts: Type 1 - 44.5 Type 2 - 9
Type 3 - 18.5 Type 4 - .5
Type 5 - 0

Type 1 conflicts by approach volume — 1 per 94.8 veh.
Type 1 conflicts by left-turn volume — 1 per 12.3 veh.
Type 2 conflicts by approach volume — 1 per 468 veh.
Type 2 conflicts by left-turn volume — 1 per 60.8 veh.
Type 3 conflicts by approach volume — 1 per 228 veh.

Figure 10. Site 10. Rte. 234 - Rte. 668, Prince William County.

Approach volume — 8,272 Speed limit 45 mph (72 kph)
Left-turn volumes: On green ball — 491
On green arrow — 734
Average daily conflicts: Type 1 - 50 Type 2 - 13.5
Type 3 - 12 Type 4 - 0
Type 5 - 0

Type 1 conflicts by approach volume — 1 per 165 veh.
Type 1 conflicts by left-turn volume — 1 per 9.8 veh.
Type 2 conflicts by approach volume — 1 per 612 veh.
Type 2 conflicts by left-turn volume — 1 per 36.4 veh.
Type 3 conflicts by approach volume — 1 per 689 veh.

This phenomenon is a pure and simple case of drivers being used to one type of signal at a particular location and finding it difficult to change their behavior after the signal is modified. In fact, the installation of new E/P signals at intersections not previously signalled (sites 5 and 7) caused relatively low conflict rates. Finally, observers noticed that intersections with several right-turn-on-red (RTOR) alternatives often resulted in driver confusion and the accompanying conflicts. The reader will note that site 2 was quite problematic in that it had the highest incidence of types 1, 2, and 3 conflicts. Moreover, it had the highest ratio of type 1 conflicts to total volume and green-ball-turn volume as well as type 2 conflicts to total volume and green-ball-turn volume. This intersection had the highest approach and turn volumes of all those evaluated. It is likely that while several variables may be the cause of the high conflict rate here, the obvious culprit is the number of movements occurring at the intersection. There are 16 different traffic movements, including four RTORs and two legal U-turns. This complexity of movements, coupled with the unusual geometrics of the southbound lane (descending hill approaching intersection, ascending hill away from intersection) and the high approach and left-turn volumes, makes a situation where conflicts are likely to occur.

Attitudinal Questionnaire Responses by Site

Table 6 is included to illustrate the variations in attitudes towards the ten sites. The table implies that generalizations as to a public attitude relative to all E/P signal treatments are probably inappropriate. Since the respondent evaluation encompasses such a wide variety of intersection locations and residential conditions these evaluations should be related for the most part to individual sites. The most that can be ascertained from the table is that citizens are generally in favor of the E/P signal, that driver confusion with the signal dissipates over time, and that the majority of drivers feel that the signals reduce intersection delay. Whether or not the E/P signal was thought to be hazardous varied enough from intersection to intersection that no generalization can be made.

Table 6

Attitudinal Questionnaire Responses by Site
(By Percentage)

Response	Site Number									
	1	2	3	4	5	6	7	8	9	10
Confused by E/P signal at first	3.6	36.5	17.2	38.3	31.8	26.2	6.5	50.0	61.5	71.4
Confused by E/P signal now	0	9.5	10.3	19.1	4.5	8.2	0	27.3	9.6	38.1
Intersection delay reduced	71.4	81.0	69.0	76.6	86.4	88.5	83.9	77.3	73.1	52.4
E/P signal has resulted in hazard	3.6	33.3	6.9	51.1	9.1	9.8	3.2	45.5	40.4	73.8
Involved in crash or near miss	14.3	13.5	13.8	21.3	13.6	27.9	16.1	40.2	17.3	42.9
Previous experience with E/P signal	71.4	57.9	58.6	31.9	63.6	55.7	71.0	40.9	32.7	21.4
In favor of E/P signal	78.6	74.6	72.4	55.3	90.9	85.2	93.5	63.6	61.5	33.3
Opposed to E/P signal	3.6	14.3	10.3	21.3	4.5	4.9	6.5	31.8	21.2	54.8

RESULTS OF ACCIDENT ANALYSES

Accident data for periods before and after installation of the signals were analyzed. Where possible, this analysis included one-year periods before and after installation. For three of the sites, due to the recency of the installation, only limited "after" data were available (3 to 6 months). For four sites, no before data were available.

Table 7 shows the total number of accidents occurring at four intersections in the one-year periods before and after installation of the E/P signals. While there was a decline in the total number of accidents over the two-year period, the number of left-turn accidents increased. However, the breakdown at individual sites showed that the data from one site probably skewed this table such that very little can be said about the increase or decrease in left-turn accidents during the one-year period after the E/P signal was installed.

Table 7

One Year Before and After E/P Installation Accident Summary
(Four Sites)

Location	All Accidents		Left-Turn Accidents	
	Before	After	Before	After
Site #4 - Rte. 29 & Fashion Square	11	22	0	14
Site #5 - Rte. 10 & Rte. 638	6	3	0	1
Site #6 - Rte. 60 & Greenwell Road	47	27	12	4
Site #7 - Rte. 11 & Rte. 623	6	6	4	4
TOTAL	70	58	16	23

Table 8 shows the monthly distribution of all accidents subsequent to the installation of the E/P signals. As can be seen, the number of accidents tended to decrease over time. In the first six months there was an average of 1.95 accidents per month per intersection. During the second six months this number was reduced to 1.03 accidents. The decrease in left-turn accidents, however, was not as drastic. In the first six months after the E/P signal was installed there was an average of 0.63 left-turn accidents per month per intersection. During the next six months this rate was reduced to 0.53 accident . Also, the table shows that left-turn accidents comprise anywhere from 100% to 23% of the total accidents occurring at the eight intersections. In the first six months after E/P installation, 40.5% of the accidents recorded were related to left turns; in the next six months 60.0% of the accidents were left-turn related. Thus, no conclusions can be drawn from these data as to what effect the passage of time has on the accident rate at E/P signalized intersections. The data are simply too limited. A more in-depth analysis of, say, 25 to 40 intersections would be needed before any such conclusions could be drawn.

Table 9 presents perhaps the most conclusive evidence regarding the effect E/P signals might have on intersection accident rates. Here, before and after accident data for seven E/P signal sites are shown. Of the seven sites shown, left-turn accidents increased almost 20% during periods after installation. It should be pointed out that not much can be said about individual intersections, except that the higher volume intersections appear to show the greatest propensity for left-turn accidents. Individual intersection analyses would require more data that take into account the myriad intersection characteristics which impact accident rates.

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Table 8

Distribution of Accidents by Month After E/P Installation
(8 Sites)

Month After Installation	Site # 2		4		5		6		7		8		9		10		Avg. Total Accidents Per Site Reported	Avg. LT Accidents Per Site Reported	Percentage LT Accidents to Total Accidents
	AA*	LTA**	AA	LTA	AA	LTA	AA	LTA	AA	LTA	AA	LTA	AA	LTA	AA	LTA			
1	7	3	2	2	0	0	2	0	0	0	0	0	5	4	3	1	2.4	0.75	53
2	4	3	3	3	0	0	2	0	0	2	0	0	0	0	2	2	1.5	1.25	73
3	2	0	1	0	1	0	4	0	4	1	0	0	3	1	4	4	2.4	0.75	37
4	2	1	0	0	1	0	4	0	1	0	3	0	2	1	-	-	1.9	0.29	23
5	3	1	2	1	1	1	4	0	0	0	0	0	-	-	-	-	1.7	0.33	30
6	3	0	3	1	0	0	3	1	0	0	2	1	-	-	-	-	1.8	0.33	27
7	-	-	3	2	0	0	5	1	0	0	2	1	-	-	-	-	2.0	0.80	40
8	-	-	1	1	0	0	2	1	0	0	5	1	-	-	-	-	1.6	0.60	38
9	-	-	2	2	0	0	0	0	0	0	1	0	-	-	-	-	0.6	0.40	67
10	-	-	0	0	0	0	1	1	0	0	0	0	-	-	-	-	0.2	0.20	100
11	-	-	4	3	0	0	0	0	0	0	2	2	-	-	-	-	1.2	1.00	83
12	-	-	1	0	0	0	0	0	1	1	1	0	-	-	-	-	0.6	0.20	33
TOTALS	21	8	22	15	3	1	27	4	6	4	16	5	10	6	9	7	1.49	0.58	44

*AA — All Accidents

**LTA — Left-Turn Accidents

Table 9

Percentage of Left-Turn Accidents for Reporting Periods Before and After E/P Installation (7 sites)

Site	Length of Reporting Period	Accidents in Before Period			Accidents in After Period			% Change in LT Accidents
		Total	LT	% LT of Total	Total	LT	% LT of Total	
2	6 mo.	13	5	38.5	21	8	38.1	- 0.4
4	12 mo.	11	0	-0-	22	15	68.2	+68.2
5	12 mo.	6	0	-0-	3	1	33.3	+33.3
6	12 mo.	47	12	25.5	27	4	14.8	-10.7
7	12 mo.	6	4	66.7	6	4	66.7	-0-
9	4 mo.	4	1	25.0	10	6	60.0	+35.0
10	3 mo.	5	3	60.0	9	7	77.8	+17.8
	TOTAL	92	24	26.1	98	45	45.9	+19.8

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APPENDIX A

PARTMENT OF HIGHWAYS & TRANSPORTATION
HAROLD C. KING, COMMISSIONER

LEO E. BUSSER, III
DEPUTY COMMISSIONER AND
CHIEF ENGINEER

CAR K. MABRY
DIRECTOR OF PLANNING

UNIVERSITY OF VIRGINIA
DR. FRANK L. HEREFORD, JR., PRESIDENT

SCHOOL OF ENGINEERING & APPLIED SCIENCE
JOHN E. GIBSON, DEAN

DR. LESTER A. HOEL, CHAIRMAN
DEPARTMENT OF CIVIL ENGINEERING

COMMONWEALTH of VIRGINIA

HIGHWAY & TRANSPORTATION RESEARCH COUNCIL

BOX 3817 UNIVERSITY STATION
CHARLOTTESVILLE, VIRGINIA 22903

)WARD H. NEWLON, JR.
:SEARCH DIRECTOR

July 27, 1981

IN REPLY PLEASE REFER TO FILE NO. 23.7.62

Dear Motorist:

The Virginia Department of Highways and Transportation recently installed new left-turn signals at the intersection of Route 29 North and Greenbrier Drive near Stromberg-Carlson. Since this type of signal is fairly new to Charlottesville, we would like to find out what motorists think of it. The purpose of this new design is to reduce motorist delay by allowing left turns onto Greenbrier Drive while the signal is green for oncoming Route 29 southbound traffic.

To find out how well the signal is achieving its purpose, we are asking motorists to fill out and mail back to us the enclosed questionnaire. By returning it you will provide information that will be of value to our traffic engineers in planning the future use of this type of signal. All information will be kept strictly confidential and be used for research purposes only.

If you do not drive or never use this intersection, please indicate this in question 1 and return the questionnaire anyway.

Thank you for your assistance.

Very truly yours,

Michael A. Perfater
Research Scientist

MAP:sk
Enclosure
cc: Mr. H.H. Newlon, Jr.
Mr. R. N. Robertson

APPENDIX B

LEFT-TURN SIGNALIZATION QUESTIONNAIRE

INTERSECTION RT. 29N. & GREENBRIER DRIVE

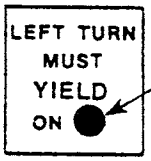
(Please circle your answer)

1. About how many times each week do you make a left turn at the pictured intersection?
   A. 1 - 2
   B. 3 - 5
   C. 6 - 10
   D. 11 or more
   E. Do not use the intersection

2. Do you find the meaning of the signal indications confusing? A. yes B. no

3. Did you find the signal confusing the first time you passed through the intersection?
   A. yes B. no

4. At what location do you feel the sign pictured here would be most helpful?



(Green in color on the actual sign)

   A. Adjacent to the signal
   B. In the median
   C. Both
   D. None necessary
   E. Other _____

5. If you knew about the new signal before it was installed how did you find out about it?
   A. Newspaper
   B. Television
   C. Radio
   D. Word of Mouth
   E. Didn't know about it
   F. Other _____

6. What type of advance publicity on the installation of a new signal do you think is most helpful?
   A. Newspaper
   B. Television
   C. Radio
   D. Mailers
   E. None
   F. Other _____

7. Do you feel the signal has reduced delays at the intersection? A. yes B. no

8. Do you feel the signal has created a hazard? A. yes B. no

9. Have you been involved in an accident or a near miss at this intersection? A. yes B. no

10. Have you seen this type of signal in other cities or states? A. yes B. no

11. What is your general opinion of this type of signal? A. In favor B. Neutral C. Against

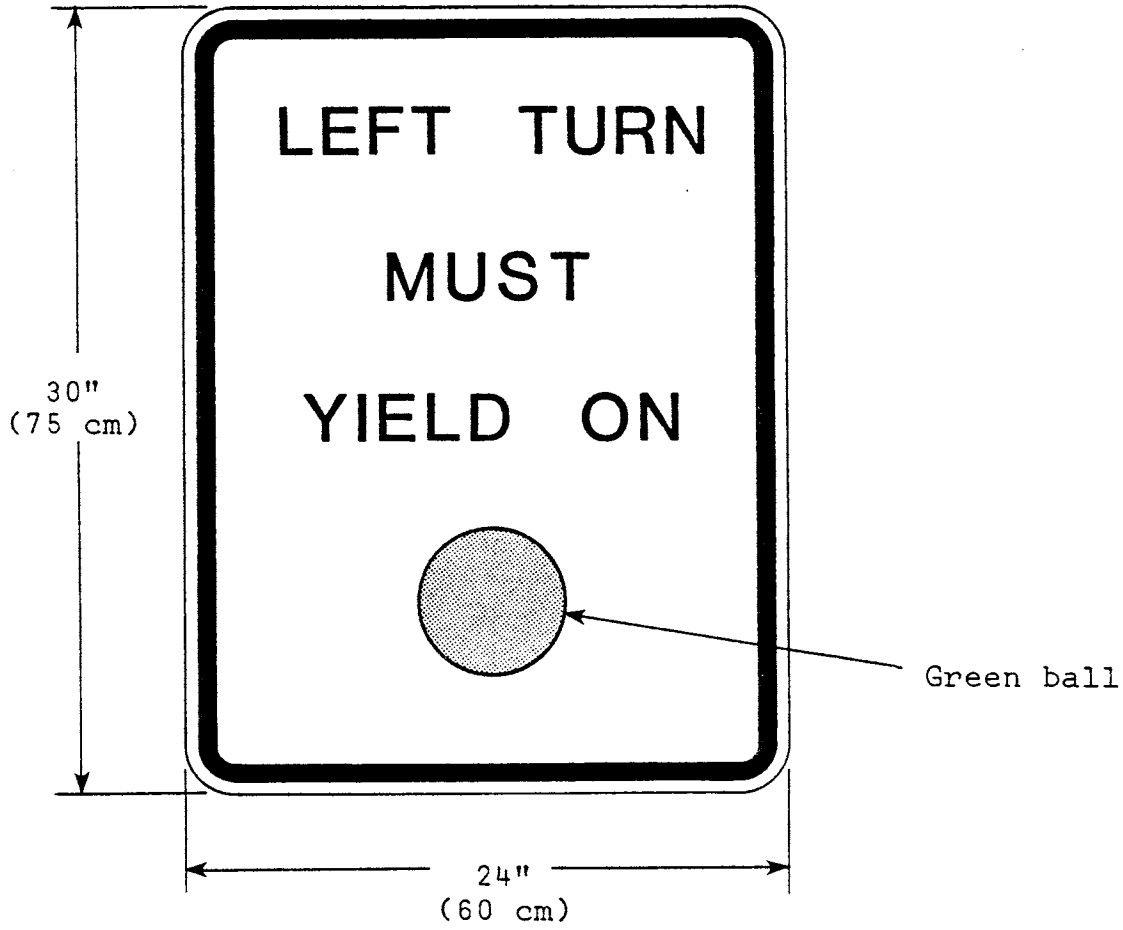
12. We would be interested in any comments or suggestions you might have concerning this type of signal. _____

_____

_____

Thank you. Please fold and mail.

APPENDIX C



Supplemental exclusive/permissive regulatory sign.