Guidelines for the Use of Protected/Permissive Left-Turn Phasing

Kenneth R. Agent
University of Kentucky, ken.agent@uky.edu
Dear Mr. Johnson:

Subject: Implementation Statement
Research Project KYHPR 85-108, Subtask No. 1
Guidelines for the Use of Protected/Permissive Left-Turn Phasing

As a result of the subject study, the following guidelines will be incorporated in the Department's Division of Traffic Guidance Manual and will become the Department's policy:

PROTECTED/PERMISSIVE LEFT-TURN PHASING

Protected/permitive traffic signal phasing can be defined as signal phasing used at an intersection where left-turns have a separate turning lane and where, during a portion of the phase, the left-turn movement is protected from through traffic while proceeding through the intersection by a green arrow and then it is also allowed to move through the intersection unprotected on a green ball during the remainder of the subject signal phase.

This type phasing serves to increase intersection capacity, but also may increase left-turn accidents under certain conditions.

Protective/permitive phasing may be used, except at approaches where the following conditions prevail. Approach conditions where protected/permitive left-turn movements should not be used:

1. Speed limit is over 45 MPH.
2. Protected-only phasing currently in operation and speed limit over 35 MPH.
3. Left-turn movement must cross three or more opposing through lanes.
4. Intersection geometrics force the left-turn lane to have a separate signal head.
5. Dual left-turn-only lanes on the approach.
6. A left-turn accident problem exists.
7. There is not adequate sight distance for opposing traffic.

When protected/permissive phasing is used, the signal head for left-turn traffic should be located above the line separating the left-turn lane from the adjacent through lane so that the left-turning traffic does not have a separate signal head. Lens arrangement "s" should be used when the protected portion of the phase is leading and lens arrangement "m" should be used when the protected portion of the phase is lagging. Figure 4-1, Section 4B-9, MUTCD. Regulatory sign R10-12 may be used with protective/permissive phasing.

The objective of this Quick Response Study was met in that the traffic engineer may decide whether permissive/left-turn phasing is appropriate to use at a given location.

Very truly yours,

R. K. Capito, P.E.
State Highway Engineer
Guidelines for the Use of Protected/Permissive Left-Turn Phasing

The objective of this study was to develop guidelines that may be used to aid the traffic engineer in deciding whether protected/permisssive (permisssive) phasing is appropriate to use at a given location. An inventory identified 58 intersections in Kentucky where permisssive phasing was used. Characteristics of these intersections were related to accident data to determine the effect permisssive phasing has had on left-turn and total accidents.

Left-turn accidents increased dramatically when permisssive phasing replaced protected-only (exclusive) phasing and when it was used at approaches where the speed limit was over 45 mph. There were no substantial changes in left-turn and total accidents when permisssive phasing was part of the original signal installation or was the first left-turn signal at an existing signal and where the speed limit was 45 mph or less.

When a left-turn signal is warranted, permisssive phasing should be used because of the reduced delay compared to exclusive phasing, unless the intersection has certain characteristics for which permisssive phasing would create an increased accident potential. A list of conditions that would preclude the use of permisssive phasing is presented.

Study Title: Quick Response Studies
Prepared in cooperation with the U. S. Department of Transportation, Federal Highway Administration

Form DOT F 1700.7 (8-72)
GUIDELINES FOR THE USE OF PROTECTED/PERMISSIVE LEFT-TURN PHASING

by

Kenneth R. Agent
Transportation Research Engineer

Kentucky Transportation Research Program
College of Engineering
University of Kentucky
Lexington, Kentucky

in cooperation with
Transportation Cabinet
Commonwealth of Kentucky

and

Federal Highway Administration
US Department of Transportation

The contents of this report reflect the views of the author who is responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the University of Kentucky, the Kentucky Transportation Cabinet, nor the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

August 1985
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>I. Introduction</td>
<td>1</td>
</tr>
<tr>
<td>II. Review of Literature</td>
<td>1</td>
</tr>
<tr>
<td>A. Accident Analysis</td>
<td>1</td>
</tr>
<tr>
<td>B. Guidelines for Use</td>
<td>3</td>
</tr>
<tr>
<td>III. Procedure</td>
<td>5</td>
</tr>
<tr>
<td>IV. Results</td>
<td>6</td>
</tr>
<tr>
<td>A. Inventory</td>
<td>6</td>
</tr>
<tr>
<td>B. Accident Analysis</td>
<td>8</td>
</tr>
<tr>
<td>C. Characteristics of Related Accidents</td>
<td>9</td>
</tr>
<tr>
<td>V. Summary</td>
<td>11</td>
</tr>
<tr>
<td>VI. Recommended Guidelines</td>
<td>12</td>
</tr>
<tr>
<td>VII. Implementation</td>
<td>13</td>
</tr>
<tr>
<td>VIII. References</td>
<td>14</td>
</tr>
</tbody>
</table>
INTRODUCTION

Turning left across opposing traffic at a signalized intersection may result in a traffic accident as well as create motorist delay. A solution to the left-turn problem may be the addition of a left-turn phase when certain guidelines are met (1). After a decision has been made to add a left-turn phase, one of two basic alternative phasing methods is commonly used. In Kentucky, the predominant type of left-turn phasing has been a protected-only type in which the left-turn driver is allowed to turn left only during the green arrow portion of the phasing, during which opposing traffic is stopped. An alternative type of phasing that has been used sparingly in Kentucky in recent years involves a combination of protected and permissive left-turn movements. During a portion of the left-turn phase, the left-turn movement is made on a green arrow and is protected from opposing traffic. In addition, left turns may be made during the remaining green through phase for the subject street when there are available gaps in opposing traffic. This is the permissive portion of the phase. Split phasing also is used in some instances.

In a previous research study, the results of replacing protected-only (exclusive) with protected/permissive (permissive) phasing at four trial intersections were studied (2). The permissive phasing provided a substantial reduction in delay and was popular to local drivers. However, there were several left-turn related accidents at those locations.

Since those initial trial installations, permissive phasing has been used at several intersections across the state. This created a larger data base that may be used to determine when permissive phasing may be used without causing an accident problem. This type of phasing has been installed at locations representing a wide range of operational and geometric conditions. This allows comparisons between those conditions and the number of left-turn related accidents. Factors affecting accident potential may then be identified. The objective of this study was to develop guidelines to aid traffic engineers in deciding whether permissive left-turn phasing is appropriate for use at a given location.

REVIEW OF LITERATURE

ACCIDENT ANALYSIS

Several previous studies have investigated the effects permissive phasing has had upon traffic accidents. In a prior study at four intersections in Kentucky, the replacement of exclusive with permissive phasing resulted in an increase in total accidents because left-turn accidents increased (2). The increase was highest at one intersection where the speed limit was 55 mph. The number of left-turn accidents decreased as drivers became more familiar with the signals.

A study by the Florida Section of the Institute of Transportation Engineers (ITE) included an accident analysis (3). At 17 intersections at which phasing was changed from protected only to
protected/permissive, the annual number of left-turn accidents per approach increased from 0.5 before to 2.5 after, and the annual total of other intersection accidents increased from 12 before to 14.5 after. At 11 intersections at which phasing was changed from protected/permissive to protected only, the annual number of left-turn accidents decreased from 5 before to 2.5 after while the annual total of other intersection accidents increased from 19 before to 31.5 after. The large decrease in the number of left-turn accidents at those 11 intersections was because they were not appropriate locations for the use of protected/permissive phasing.

Another study reported the accident experience at nine sites in Maryland (4). At two sites where protected/permissive phasing was the original left-turn phasing used, the annual number of left-turn accidents per intersection (each intersection had protected/permissive phasing on two approaches) increased from 3 before to 4.5 after. The annual number of rear-end accidents per intersection decreased from 5 before to 2.5 after and the annual total number of accidents per intersection decreased from 14.5 before to 12.5 after. At seven sites where protected-only phasing was replaced with protected/permissive, the annual number of left-turn accidents increased from 4.1 before to 5.9 after while the annual number of rear-end accidents decreased from 9.2 to 6.4 and the annual total number of accidents decreased from 26.5 to 18.6.

A Federal Highway Administration report summarized accident data at a few intersections in California (5). The conclusion was that the use of permissive left-turn phasing at locations with no prior left-turn phasing may not increase accidents, but replacing protected with permissive phasing may result in an increase in left-turn related accidents. At six intersections where protected phasing was replaced with permissive, the annual number of left-turn accidents increased from 0.8 to 3.4 while the annual number of rear-end accidents decreased from 1.0 to 0.4 and the annual total number of accidents increased from 6.2 to 7.3.

Relative left-turn accident rates for various left-turn signalization schemes were listed in another report (6). Relative to a value of 1.0 for no phasing, protected only phasing was given a value of 0.10 while protected (leading)/permissive was rated 0.35 and permissive/protected (lagging) was rated 0.73.

Accidents were summarized at seven sites in Virginia where exclusive/permissive phasing was installed (7). Considering before and after periods of equal length at each site, the number of left-turn accidents increased from 24 before to 45 after while the total number of accidents increased from 92 before to 98 after.

A report by the Southern California Section of ITE concluded that left-turn experience with protected/permissive phasing was comparable to conventional two-phase operation (8). Accident studies at seven intersections in Los Angeles found eight left-turn accidents before and six after replacement of two-phase phasing with protected/permissive.
Another Maryland study comparing exclusive and exclusive-permissive left-turn signal phasing concluded that, at intersections with good geometrics, the accident history for these signals did not differ significantly (9). An accident history comparison found 1.98 left-turn accidents per year at intersections having exclusive phasing compared with 2.68 accident per year at exclusive-permissive (EP) phasing locations (one EP location was omitted due to its unique accident history). It was also concluded that, when an EP location has more than six left-turn accidents in one year, it has an abnormally high left-turn accident history.

Left-turn accident rates (left-turn accidents per one million left-turning vehicles) were calculated by type of left-turn phasing in another study (10). The rate was lowest for exclusive phasing (0.97) and highest where no left-turn phasing was provided (3.68). Exclusive/permissive phasing had a rate (2.24) between those two rates.

Average annual left-turn accident rates for an approach in terms of accidents per 100 million left turning plus opposing vehicles was calculated in another study (11). The study sites included 20 intersections having exclusive/permissive phasing, 15 intersections having exclusive phasing, and 10 having no left-turn phasing. The rate for exclusive/permissive phasing (55.8) was much higher than that for exclusive phasing (14.0) or for no left-turn phasing (16.8).

GUIDELINES FOR USE

Several studies have listed guidelines for the use of protected/permissive phasing. A detailed set of guidelines was included in a report by the Florida Section of ITE (3). That report stated that protected/permissive left-turn phasing should be provided for all intersection approaches requiring a left-turn phase unless there is a compelling reason for using another type of left-turn phasing. Conditions where protected only phasing should be used include the following:

1) existence of double left-turn only lane,
2) intersection geometrics force the left-turn lane to have an exclusive signal head,
3) sight distance of less than 250 feet when speed of opposing traffic is 35 mph or less or less than 400 feet when opposing traffic speed is 40 mph or more, or
4) approach is lead portion of lead/lag intersection phasing sequence.

Either of the following conditions, along with the judgment that permissive left turns would be hazardous, could be used to show protected only phasing might be appropriate:

1) poor sight distance due to geometrics or opposing left-turn vehicles,
2) speed limit of opposing traffic greater than 45 mph,
3) left-turn traffic must cross three or more lanes,
4) more than six left-turn accidents in one year on approach with protected/permissive phasing, or
5) unusual intersection geometrics make protected/permissive phasing confusing.

Permissive/protected phasing could be used under the following situations:

1) approach to T-intersection where opposing U-turns are prohibited,
2) approach to 4-way intersection where opposing approach has prohibited left turns or protected-only left-turn phasing, or
3) opposing approaches to a 4-way intersection where left-turn volumes are similar.

Split phasing could be used under the following conditions:

1) opposing approaches offset,
2) left-turn volumes very heavy and nearly equal to through movement,
3) left-turn volume heavy and no separate left-turn lane provided, or
4) drivers may turn left from more than one lane but also may use the right-most left-turn lane as a through lane.

A flow chart was developed in another report to determine the need for either exclusive or exclusive/permissive left-turn phasing (10). Left-turn phasing was indicated to be needed when left-turn demand in the peak hour was greater than two vehicles per cycle and the product of left-turn and opposing vehicles was greater than 144,000 for two opposing lanes and 100,000 for three opposing lanes. Exclusive/permissive phasing was recommended unless

1) the opposing speed was greater than 45 mph,
2) there were three opposing lanes,
3) sight distance was restricted (less than 250 feet when speeds were 35 mph or less or less than 400 feet when speeds are 40 mph or more), or
4) a severe accident problem exists.

The previous Kentucky study that evaluated permissive phasing recommended that such phasing should be considered at all new left-turn phasing locations and not be limited to T-intersections (2). Limitations to its use would be where sight distance was restricted or possibly where the speed limit was over 45 mph.

Criteria were also presented in a report from Maryland concerning the use of exclusive or exclusive-permissive phasing (9). Exclusive-permissive phasing could be used when

1) a large delay was experienced with exclusive phasing,
2) opposing and left-turn volumes are moderate allowing gaps for or left turns, or
3) low-volume intersections with periods free of traffic.
Conditions in which exclusive-permissive phasing might result in operational difficulties included the following:

1) median width over 20 feet,
2) presence of median and the lane opposite permissive phase has more than 20 percent of trucks large enough to obstruct view of oncoming traffic,
3) insufficient sight distance to see adequate gap,
4) the stopping sight distance for opposing through traffic meets or exceeds the distance it would travel during an acceptable gap,
5) speed of opposing traffic high or subject to fluctuations, or
6) presence of double left-turn lanes.

A detailed list of guidelines also was developed for the use of exclusive/permissive phasing in a Virginia study (11). Exclusive/permissive phasing was recommended for consideration when

1) the product of the left-turn and opposing peak hour volume divided by the number of lanes is between 50,000 and 200,000 and the left-turn volume exceeds two vehicles per cycle during the peak hour,
2) the mean peak hour delay per left-turning vehicles exceeds 35 seconds and the total peak hour left-turn delay exceeds two vehicle hours,
3) adequate sight distance exists for the left-turning vehicles or opposing through traffic,
4) there are no more than two lanes of opposing through traffic,
5) there are no intersection geometrics that promote hazardous conditions,
6) there is good access management, and
7) the annual exclusive/permissive delay savings is greater than or equal to the annual exclusive accident savings.

Left-turn accidents and conflicts were used to determine if a safety problem existed at an exclusive/permissive site. The accident criteria were an annual number of left-turn accidents greater than five and an accident rate exceeding the critical based on a mean of 32.6 accidents per 100 million left-turn plus opposing volume. The conflicts criteria were over 39 total conflicts in the total period (6.5 hours including a 4.5-hour off-peak and a 2-hour peak period) and the total left-turn conflict rate greater than the critical rate based on a mean of 4.0 left-turn conflicts per 100 left turns.

PROCEDURE

A survey of the highway districts in which permissive phasing has been installed was conducted. The survey form used is shown in Figure 1. The form was divided into the following sections: 1) location, 2) general information, 3) volume information, and 4) intersection timing. From the location information, the intersection at which the phasing was installed could be determined. The general information
provided data such as installation data and whether the phasing was part of the original signal installation or if it replaced exclusive phasing. In many cases, the volume and timing information was unavailable.

After the permissive phasing locations were identified, each site was visited, and the data sheet shown in Figure 2 was completed. Photographs were taken at each intersection at certain distances from the intersection. Traffic speeds on the approach opposing the left turn were obtained, and the dimensions of the intersections were measured.

Using the location information and installation date, before-and-after accident data were collected. In some cases, the phasing had been installed for several years so that before accident data were not available. Also, in cases of very recent installations, one year of after data, which was considered to be minimum, was not available. Data were summarized into one-year increments. Two years of before data were collected when possible. The period of after data varied from one year to seven years. Copies of the accident report of all related left-turn accidents were obtained and information was summarized from those reports.

RESULTS

INVENTORY

The statewide survey located 58 intersections at which permissive phasing was in operation. Most were "T" intersections with the phasing used on only one approach. There were five "4-way" intersections. Four had permissive phasing on two approaches and one had permissive phasing operating on all four approaches. This resulted in data being summarized for a total of 65 approaches.

As noted in the procedures section, a field inspection of all 58 intersections was conducted. A summary of the locations having permissive phasing is given in Table 1. As would be expected, Lexington and Louisville had the highest number. Lexington had the highest number of intersections with 20 followed by Louisville with 12. The only other city having more than two was Owensboro with five.

Characteristics of the permissive phasing locations are summarized in Table 2. This summary was tabulated from data collected and the speed study that was conducted at each location. Data are summarized by approach.

In most instances, the speed limit was 35 mph or less (60 percent). The speed limit was greater than 45 mph at only four approaches (6 percent). The speed studies found that the 85th percentile speed was between 36 and 45 mph in most instances. For seven approaches, the 85th percentile speed was greater than 45 mph. Sight distance and resulting sight time, which was calculated by dividing sight distance by the average speed, was generally very good. In only one instance was the sight distance less than 250 feet (the sight time was 4 seconds at that approach). Almost one half (45 percent) of the approaches had a sight distance exceeding 1,000 feet.
Typical arrangements of lens in signal faces are given in the Manual on Uniform Traffic Control Devices for Streets and Highways (MUTCD) (12) and are shown in Figure 3. The previous Kentucky study (2) recommended the use of arrangement "s" when the protected portion of the left-turn phase was leading and arrangement "g" when it was lagging. Arrangement "s" was used in most instances and most installations involved leading phasing. Arrangement "s" was used for 38 of the 52 approaches having leading phasing and 11 of the 12 approaches having lagging phasing. Arrangement "m" was used for nine approaches having leading phasing. Arrangement "g" was used for five approaches having leading phasing and one approach with lagging phasing.

The previous report (2) also recommended that the signal head controlling the permissive phasing be placed on the line separating the left-turn lane and adjacent through lane. This signal head was positioned in this manner on 38 approaches (58 percent). The position of this signal head was related to the presence of a separate left-turn lane. Of the 46 approaches having a separate left-turn lane, 34 (74 percent) had this signal head on the line separating the left-turn lane and adjacent through lane. For 15 of the 19 approaches having no separate left-turn lane, this signal head was positioned in the middle of the left lane.

The previous report (2) also recommended that the left-turn movement should not have a separate signal head so that there would be only two signal heads for the approach rather than three. For 55 approaches (85 percent), two signal heads were provided. There were only two signal heads at all of the approaches having no separate left-turn lane. For 36 of the 46 approaches having a separate left-turn lane, only two signal heads were provided.

In 23 cases, there was one through lane opposing the left-turn movement; and at 42 locations, there were two opposing through lanes. No locations had more than two opposing lanes.

The previous report (2) also recommended use of the regulatory sign shown in Figure 4. Slightly less than one half (30 of 65 or 46 percent) had signing. There was an overhead sign on 22 approaches, six approaches had both overhead and ground-mounted signs, while two approaches had only a ground-mounted sign.

The method by which the permissive phasing was installed was also found for each intersection. In 25 instances, the phasing was installed as part of the original signal installation. In 28 cases, a signal was in place before the permissive phasing was added, but it was the first left-turn phasing used. For 12 approaches, the permissive phasing replaced exclusive left-turn phasing.

It was noted that most of the approaches have activated rather than pre-timed control (82 percent). Also, about one half of the approaches were part of a coordinated signal system.
The dates of installations were obtained. The use of permissive phasing in Kentucky has been a recent development. Almost one half (46 percent) of the signals were installed since the end of 1980.

ACCIDENT ANALYSIS

A before-and-after accident analysis was performed using the 44 approaches that had both before and after accident data available. Summaries from this analysis are presented in Table 3. The average numbers of left-turn and total accidents per approach per year before and after installation of permissive phasing are given as a function of several intersection characteristics. Considering all 44 approaches, the average number of left-turn accidents per year per approach increased from 1.1 to 2.1 after installation of permissive phasing while the average total accidents per year per approach decreased from 9.7 to 8.7. Part of this reduction in total accidents can be attributed to a reduction in rear-end accidents per year per approach from 3.0 to 2.5.

There was a large variation in the effect on left-turn accidents depending upon the type of signal present before the permissive phasing was implemented. For new signal installations or when permissive phasing was the first left-turn signal, there was little effect on left-turn accidents and there was a reduction in total accidents. However, there was a large increase in left-turn accidents when permissive replaced exclusive phasing, but total accidents did not increase.

There was a significant increase in left-turn accidents at higher speed locations. For speed limits of 35 mph or less, the number of left-turn and total accidents decreased slightly after installations of permissive phasing. For speed limits of 40 and 45 mph, the after data showed an increase in accidents, especially left-turn accidents. For speed limits above 45 mph, there was a dramatic increase in accidents.

Since these two variables were found to have such an effect upon numbers of accidents, an analysis was performed using combinations of the type of signal before implementation of the permissive phasing and the speed limit. For new signal installations, the addition of permissive phasing did not substantially increase the number of accidents, regardless of speed limit. For intersections where permissive phasing was the first left-turn signal, accident numbers were not dramatically affected for speed limits of 45 mph or less, but accidents increased significantly at the one approach having a speed limit exceeding 45 mph. Where permissive replaced exclusive phasing, there were dramatic increases for those intersections having a speed limit exceeding 35 mph but no change at the one intersection where the speed limit was 35 mph or less.

Using the information from Table 3, an additional summary of before and after data was performed using data at "new signal" or "first left-turn signal" locations having speed limits of 45 mph or less. Data were available at 30 approaches which met these criteria and are summarized in Table 4. When all 30 approaches were considered, the before and after numbers of accidents, especially left-turn accidents, were very similar. The effects from the type of signal before installation of the
permissive phasing and speed limit would not be present in this set of approaches so the effects of other variables could be analyzed.

A comparison of approaches with and without the regulatory sign, as shown in Figure 4, revealed that the presence of the sign did not reduce the number of related accidents. Intersections without the sign actually had fewer related accidents in the after period than intersections having the regulatory sign.

There were fewer related accidents when the signal head position was between the left-turn and adjacent through lane rather than in the middle of the left-turn lane. Also, there were fewer related accidents when there were two, rather than three, signal heads for an approach. Three signal heads were present when there was a separate signal head for the left-turn movement.

For all the approaches in the analysis presented in Table 4, the protection portion of the phase was leading. The analysis by signal head configuration shows that configuration "s," as shown in Figure 3, provided the best results in terms of related accidents.

The analysis also showed that permissive phasing provided better results for approaches having no separate left-turn lane compared with an approach having a separate left-turn lane.

The product of the left-turn and opposing volume was used as a volume warrant for left-turn phasing in a previous report (1). Approaches with two opposing lanes having a peak-hour volume product exceeding 100,000 were considered as those needing a left-turn phase. Using the limited data available, accidents were similar for approaches below and above the volume warrant.

A summary of "after" left-turn accidents at the 61 approaches for which at least one year of after data were available is shown in Figure 5. Forty-eight approaches (79 percent) had an average of three or less left-turn accidents per year per approach. Also, the highest number of left-turn accidents in any one year at 39 approaches (64 percent) was less than four. Five approaches having a high of 10 or more related accidents in one year were locations at which exclusive phasing had been replaced.

CHARACTERISTICS OF RELATED ACCIDENTS

Selected information was summarized from the accident reports of the related left-turn accidents. Left-turn accidents totaled 517 for approaches having permissive phasing. A comparison of some of the characteristics of left-turn accidents with statewide accidents is given in Table 6.

The overall severity of the related left-turn accidents was higher than statewide accidents. The percentage of total or injury accidents was 37.1 percent for the related accidents compared to 22.1 percent statewide. However, there was only one fatal accident at the study locations, so the percentage of fatal accidents was lower than statewide.
A comparison by time of day revealed that the percentage of related accidents was higher than statewide for the time period of 6:00 p.m. through 2:59 a.m. This agrees with the finding that a higher percentage of the related accidents occurred during darkness. However, nearly all of the intersections studied had artificial lighting and only a small percentage of the related accidents occurred during darkness without artificial lighting.

The percentage of related accidents that occurred on wet pavement was very similar to the percentage for statewide accidents. Almost none of the related accidents occurred on ice or snow (one percent) compared to 8.3 percent of statewide accidents.

A comparison by month indicated that the highest percentage of related accidents occurred in October and September. Statewide, the highest percentage occurred in December and January. The largest difference when accidents are compared by day of week is a higher percentage of related accidents on Monday and Thursday and a lower percentage on Sunday. There was a higher percentage of related accidents during the weekdays and a lower percentage on the weekend.

Differences were detected when the age and sex of the left-turning driver in the related accidents were compared to all drivers in the state involved in an accident. Compared to statewide accidents, there was a higher percentage of drivers in the age category of 65 years and above involved in the related accidents. There was also a much higher percentage of female drivers involved in related accidents compared to the statewide percentage. The reason for this may be that older and female drivers drive fewer miles than those in other categories so that they have less exposure to the permissive phasing type of signal, and as a result, are more likely to be confused by such signals.

A summary by the residence of the left-turning drivers found that approximately one-fourth of those drivers did not live in the county in which the accident occurred. Since these signals are generally limited to the larger cities, out-of-county or out-of-state drivers would not be as familiar with this type phasing.

Accident reports were reviewed to determine if the driver who was turning left offered any explanation as to why he/she failed to yield the right-of-way to the opposing vehicle(s). In the large majority of cases, no explanation was given on the report. The explanation given most often (in 26 accidents) was that the left-turning driver thought he/she had the right-of-way. In 25 accidents, the driver stated that he/she did not see the oncoming vehicle. A common method of turning left when sufficient gaps are not available is to wait in the intersection until the signal turns yellow and opposing vehicles stop and then complete the left turn. In 25 cases, the left-turning driver indicated he/she turned on yellow or at the end of the cycle and the opposing driver either entered the intersection at the end of yellow or on red. The left-turning driver was not always at fault. In 21 accidents, the left-turning vehicle turned on a green arrow and the opposing vehicle disregarded the red signal. In another 20 accidents,
the driver of the left-turning vehicle thought he/she had the green arrow but the police officer was unable to determine whether that was the case.

SUMMARY

INVENTORY
1. Fifty-eight intersections were located in Kentucky at which protected/permissive (permissive) phasing was used (on a total of 65 approaches).
2. The speed limit was 35 mph or less at 39 approaches (60 percent) and over 45 mph at only four approaches (6 percent).
3. Sight distance was generally very good, with a sight distance of less than 250 feet only at one approach.
4. The signal head arrangement "s" shown in Figure 3 was used at most installations. Also, most installations involved the protected portion of the left-turn phasing leading the permissive portion. Arrangement "m" was used at most locations having lagging phasing.
5. The signal head for left-turning traffic was generally located on the line separating the left-turn lane and the adjacent through lane.
6. At most locations (85 percent), two signal heads were provided on the approach such that the left-turn movement did not have a separate signal head.
7. At no location was there more than two opposing through lanes.
8. Slightly over one half of the approaches had the regulatory sign shown in Figure 4.
9. For 25 approaches, the phasing was part of the original signal installation. For 28 approaches, the permissive phasing was the first left-turn phasing used at an existing signal. For 12 approaches, the permissive phasing replaced protected-only (exclusive) phasing.
10. Almost one half of the installations were placed since the end of 1980.

ACCIDENT ANALYSIS
1. Forty-four approaches had both before-and-after accident data available and comparisons of left-turn and total accidents could be made. For all 44 approaches, the average number of left-turn accidents per year per approach increased from 1.1 to 2.1 after installation of permissive phasing while the average total accidents per year per approach decreased from 9.7 to 8.7.
2. The number of left-turn accidents increased dramatically when permissive replaced exclusive phasing, except at the one approach where the speed limit was 35 mph or less. There was not a corresponding increase in total accidents.
3. There was a dramatic increase in left-turn accidents, as well as an increase in total accidents, when permissive phasing was used at approaches having a speed limit above 45 mph.
4. At 30 approaches at which the permissive phasing was part of the original signal installation or was the first left-turn signal at an existing signal and where the speed limit was 45 mph or less, the installation of permissive phasing resulted in a slight decrease in the numbers of left-turn and total accidents.
5. The presence of the regulatory sign shown in Figure 4 did not reduce the number of left-turn accidents.
6. There were fewer left-turn accidents when the signal head was located above the line separating the left-turn lane and adjacent through lane such that the left-turn movement did not have a separate signal head.
7. Approaches having leading phasing and signal head configuration "s," as shown in Figure 3, had a fewer number of left-turn accidents.
8. Of 61 approaches for which after data were available, 48 approaches (79 percent) had an average of three or less left-turn accidents per year per approach after the installation of permissive phasing, and the highest number of left-turn accidents in any one year was less than four at 39 approaches (64 percent).

CHARACTERISTICS OF RELATED ACCIDENTS

1. A total of 517 left-turn accidents occurred on approaches having permissive phasing at the study locations.
   2. The overall severity of the related left-turn accidents was higher than statewide accidents although there was only one related fatal accident.
   3. The percentage of left-turn accidents that occurred during darkness was higher than for statewide accidents.
   4. The percentage of related accidents that occurred on wet pavements was very similar to that for statewide accidents.
   5. The percentage of drivers turning left in the related accidents who were in the older age category and female category was higher than statewide percentages.

RECOMMENDED GUIDELINES

Protected/permissive left-turn phasing has previously been shown to provide a significant savings in time compared to protected-only phasing (2). However, the accident analysis in this report shows that it does not provide the safety to left-turning vehicles comparable to protected-only phasing. The accident history at protected/permissive locations is closer to that for locations having no left turn phasing. Therefore, it should not be used at locations having a potential or existing left-turn accident problem.

The warrants presented in the previous study should be used to determine the need for a left-turn phase (1). These warrants include 1) accident experience, 2) delay, 3) volumes, and 4) traffic conflicts. Warrants for accident experience and traffic conflicts indicate an accident problem for which protected-only phasing would be appropriate.

In summary, protected/permissive is the preferable method of left-turn phasing because of savings in time compared to protected-only phasing. However, it creates an increased accident potential and it should not be used when any of the following conditions exist:

1. speed limit is over 45 mph,
2. protected-only phasing currently in operation and speed limit over 35 mph,
3. left-turn movement must cross three or more opposing through lanes,
4. intersection geometrics force the left-turn lane to have a separate signal head,
5. double left-turn only lanes on the approach,
6. a left-turn accident problem exists (four or more left-turn accidents in one year or six or more left-turn accidents in two years on an approach (1)),
7. a potential left-turn problem exists as documented by a traffic conflicts study (1), or
8. sight distance below that given below for various speeds (speed would be the speed limit or 85th percentile speed if available) (distance is the stopping distance for the given speed assuming a perception-reaction time of 1.5 seconds and a coefficient of friction of 0.2).

<table>
<thead>
<tr>
<th>Speed (mph)</th>
<th>Minimum Sight Distance (feet)</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>160</td>
</tr>
<tr>
<td>30</td>
<td>220</td>
</tr>
<tr>
<td>35</td>
<td>280</td>
</tr>
<tr>
<td>40</td>
<td>350</td>
</tr>
<tr>
<td>45</td>
<td>440</td>
</tr>
<tr>
<td>50</td>
<td>530</td>
</tr>
<tr>
<td>55</td>
<td>630</td>
</tr>
</tbody>
</table>

When protected/permisive phasing is used, the following recommendations are made for its installation:

1. the signal head for left-turn traffic should be located above the line separating the left-turn lane from the adjacent through lane so that the left-turning traffic does not have a separate signal head,
2. lense arrangement "s," as shown in Figure 3, should be used when the protected portion of the phase is leading,
3. lense arrangement "m," as shown in Figure 3, should be used when the protected portion of the phase is lagging, and
4. no regulatory sign is necessary.

IMPLEMENTATION

The recommended guidelines may be used by the Kentucky Transportation Cabinet when deciding whether to use protected/permisive or protected-only left-turn phasing at specific intersections. These guidelines may be incorporated into the guidance manual developed by the Division of Traffic.
REFERENCES


**LOCATION:**

County ___________________ City ___________________

Route Number and/or Street Name ______________________________________

Milepoint (if applicable) ____________________________________________

Intersection Route Number and/or Street Name __________________________

**GENERAL INFORMATION:** Date Installed ____________________________

Was permissive phasing added as part of original signal installation? Yes No

If no, did permissive phasing replace exclusive phasing? Yes No

Is an advisory sign relating to permissive phasing used? Yes No

**Type of Control:** Actuated_________________

Pre timed_________________

**Co-ordinated System:** Yes No

**STREET NAME** ___________________ ADT ___________________

**VOLUME INFORMATION**

<table>
<thead>
<tr>
<th>Approach Number</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Approach Name</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8 Hr THRU Volume</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>*Peak Hr THRU Volume</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8 HR LT Turn Volume</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Peak HR LT Turn Volume</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Peak Hour THRU Volume is value in opposition to peak hour LT Turn flow of opposite approach.

**INTERSECTION TIMING**

<table>
<thead>
<tr>
<th>PHASE</th>
<th>INITIAL GREEN or FIXED # TIME</th>
<th>VEH EXT</th>
<th>MAX 1</th>
<th>MAX 1</th>
<th>YELLOW</th>
<th>RED</th>
<th>MODE*</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Mode = Min Recall, Max Recall, Lock, or NonLock

**IF CO-ORDINATED**

<table>
<thead>
<tr>
<th>PLAN #</th>
<th>TIME OF DAY/ DAY OF WEEK</th>
<th>CYCLE LENGTH</th>
<th>SPLIT</th>
<th>PLAN #</th>
<th>TIME OF DAY/ DAY OF WEEK</th>
<th>CYCLE LENGTH</th>
<th>SPLIT</th>
</tr>
</thead>
</table>

**COMMENTS:**

______________________________________________________________
Figure 2. PERMISSIVE LEFT-TURN PHASING FIELD DATA SHEET

LOCATION:

County______________________________  City______________________________

Route Number and/or Street Name__________________________________________

Approach________________________________________________________________

Intersecting Route Number and/or Street Name______________________________

FIELD DATA:

Speed Limit_______ mph

Sight Time_______ seconds

Sight Distance_______ feet

Configuration of Left-Turn Signal Head_______ Position:______________

Arrow Portion of Phase: Leading_______ or Lagging_______

Separate Left-Turn Lane: Yes_______ No_______

Number of Other Lanes_______

Number of Signal Heads_______

Number of Opposing Lanes_______

Permissive Phasing Sign: Yes_______ No_______ Position________________________

Distance to Next Intersection (If Less Than Sight Distance)_______ feet

<table>
<thead>
<tr>
<th>Permissive Phasing Approach</th>
</tr>
</thead>
</table>
Figure 3. Typical Arrangements of Lenses in Signal Faces
Figure 4. Regulatory Sign
<table>
<thead>
<tr>
<th>NO.</th>
<th>COUNTY</th>
<th>CITY</th>
<th>STREET OR ROUTE</th>
<th>STREET OR ROUTE</th>
<th>APPROACHES</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Hopkins</td>
<td>Madisonville</td>
<td>KY 70 (E Center St)</td>
<td>KY 254</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>Henderson</td>
<td>Henderson</td>
<td>US 41A (Green St)</td>
<td>Second St</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>Henderson</td>
<td>Henderson</td>
<td>US 41A (Green St)</td>
<td>First St</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>Daviess</td>
<td>Owensboro</td>
<td>Ninth Street</td>
<td>US 431 (Frederica)</td>
<td>1</td>
</tr>
<tr>
<td>5</td>
<td>Daviess</td>
<td>Owensboro</td>
<td>US 431 (Frederica)</td>
<td>Griffith</td>
<td>1</td>
</tr>
<tr>
<td>6</td>
<td>Daviess</td>
<td>Owensboro</td>
<td>US 431 (Frederica)</td>
<td>18th St</td>
<td>1</td>
</tr>
<tr>
<td>7</td>
<td>Daviess</td>
<td>Owensboro</td>
<td>18th St</td>
<td>US 231 (Tripllett)</td>
<td>1</td>
</tr>
<tr>
<td>8</td>
<td>Daviess</td>
<td>Owensboro</td>
<td>18th St</td>
<td>US 231 (Breckinridge)</td>
<td>1</td>
</tr>
<tr>
<td>9</td>
<td>Christian</td>
<td>Hopkinsville</td>
<td>US 68 (9th St)</td>
<td>US 41 (S Main St)</td>
<td>1</td>
</tr>
<tr>
<td>10</td>
<td>Jefferson</td>
<td>Louisville</td>
<td>Browns Lane</td>
<td>Dutchmans Lane</td>
<td>1</td>
</tr>
<tr>
<td>11</td>
<td>Jefferson</td>
<td>Louisville</td>
<td>Hillcrest</td>
<td>Brownsboro Rd.</td>
<td>1</td>
</tr>
<tr>
<td>12</td>
<td>Jefferson</td>
<td>Louisville</td>
<td>US 60 BR (Grinstead)</td>
<td>US 60A (Cherokee)</td>
<td>1</td>
</tr>
<tr>
<td>13</td>
<td>Jefferson</td>
<td>Louisville</td>
<td>Bardstown Rd</td>
<td>Douglas</td>
<td>1</td>
</tr>
<tr>
<td>14</td>
<td>Jefferson</td>
<td>Louisville</td>
<td>Eastern Parkway</td>
<td>U of L Driveway</td>
<td>1</td>
</tr>
<tr>
<td>15</td>
<td>Jefferson</td>
<td>Louisville</td>
<td>Taylor</td>
<td>Southern Heights</td>
<td>1</td>
</tr>
<tr>
<td>16</td>
<td>Jefferson</td>
<td>Louisville</td>
<td>Manslick</td>
<td>Crums Lane</td>
<td>1</td>
</tr>
<tr>
<td>17</td>
<td>Jefferson</td>
<td>Louisville</td>
<td>Fern Valley Rd (KY 1631)</td>
<td>I 65 SB Ent Ramp</td>
<td>1</td>
</tr>
<tr>
<td>18</td>
<td>Jefferson</td>
<td>Louisville</td>
<td>Fern Valley Rd (KY 1631)</td>
<td>I 65 NB Ent Ramp</td>
<td>1</td>
</tr>
<tr>
<td>19</td>
<td>Jefferson</td>
<td>Louisville</td>
<td>Fern Valley Rd (KY 1631)</td>
<td>Holiday Towers</td>
<td>1</td>
</tr>
<tr>
<td>20</td>
<td>Jefferson</td>
<td>Louisville</td>
<td>Hikes Lane</td>
<td>Goldsmith</td>
<td>1</td>
</tr>
<tr>
<td>21</td>
<td>Harrison</td>
<td>Cynthiana</td>
<td>US 27 (S Main St)</td>
<td>KY 32 (E Pike St)</td>
<td>1</td>
</tr>
<tr>
<td>22</td>
<td>Campbell</td>
<td>Cold Spring</td>
<td>US 27</td>
<td>E Alexandria Pike</td>
<td>1</td>
</tr>
<tr>
<td>23</td>
<td>Campbell</td>
<td>Cold Spring</td>
<td>US 27</td>
<td>KY 1998</td>
<td>1</td>
</tr>
<tr>
<td>24</td>
<td>Campbell</td>
<td>Highland Hts</td>
<td>US 27</td>
<td>Johns Hill Rd</td>
<td>1</td>
</tr>
<tr>
<td>25</td>
<td>Campbell</td>
<td>Fort Thomas</td>
<td>US 27 (Alexandria)</td>
<td>KY 445 (Grandview)</td>
<td>1</td>
</tr>
<tr>
<td>26</td>
<td>Campbell</td>
<td>Fort Thomas</td>
<td>US 27 (Alexandria)</td>
<td>Highland Ave</td>
<td>1</td>
</tr>
<tr>
<td>27</td>
<td>Campbell</td>
<td>Newport</td>
<td>Ky 9 (12 Street)</td>
<td>Brighton St</td>
<td>1</td>
</tr>
<tr>
<td>28</td>
<td>Kenton</td>
<td>Erlanger</td>
<td>US 25, 42 &amp; 127 (Dixie Hwy)</td>
<td>Hallam Ave</td>
<td>1</td>
</tr>
<tr>
<td>29</td>
<td>Kenton</td>
<td>Lakeside Park</td>
<td>US 25, 42 &amp; 127 (Dixie Hwy)</td>
<td>KY 1303 (Hudson Ave)</td>
<td>1</td>
</tr>
<tr>
<td>30</td>
<td>Kenton</td>
<td>Fort Wright</td>
<td>US 25, 42 &amp; 127 (Dixie Hwy)</td>
<td>KY 1072 (Kyles Ln)</td>
<td>1</td>
</tr>
<tr>
<td>31</td>
<td>Kenton</td>
<td>Covington</td>
<td>Madison</td>
<td>20th</td>
<td>1</td>
</tr>
<tr>
<td>32</td>
<td>Boone</td>
<td>Florence</td>
<td>Mall Rd</td>
<td>Mall Entrance</td>
<td>1</td>
</tr>
<tr>
<td>33</td>
<td>Scott</td>
<td>Georgetown</td>
<td>US 25</td>
<td>Showalter</td>
<td>1</td>
</tr>
<tr>
<td>34</td>
<td>Scott</td>
<td>Georgetown</td>
<td>US 25</td>
<td>Washington Square</td>
<td>1</td>
</tr>
<tr>
<td>35</td>
<td>Woodford</td>
<td>Versailles</td>
<td>US 60</td>
<td>US 60 Bypass</td>
<td>1</td>
</tr>
<tr>
<td>36</td>
<td>Clark</td>
<td>Winchester</td>
<td>US 60</td>
<td>KY 627 (Maple)</td>
<td>1</td>
</tr>
<tr>
<td>37</td>
<td>Montgomery</td>
<td>Mt Sterling</td>
<td>US 60</td>
<td>US 460 (Main St)</td>
<td>1</td>
</tr>
<tr>
<td>38</td>
<td>Fayette</td>
<td>Lexington</td>
<td>US 27-68 (Broadway)</td>
<td>Maxwell Street</td>
<td>1</td>
</tr>
<tr>
<td>39</td>
<td>Fayette</td>
<td>Lexington</td>
<td>US 60 (Winchester Rd)</td>
<td>Loudon Avenue</td>
<td>2</td>
</tr>
<tr>
<td>40</td>
<td>Fayette</td>
<td>Lexington</td>
<td>US 25 (Richmond Rd)</td>
<td>Jarrico</td>
<td>2</td>
</tr>
<tr>
<td>41</td>
<td>Fayette</td>
<td>Lexington</td>
<td>US 25 (Richmond Rd)</td>
<td>KY 4 (Inner)</td>
<td>1</td>
</tr>
<tr>
<td>42</td>
<td>Fayette</td>
<td>Lexington</td>
<td>US 25 (Richmond Rd)</td>
<td>KY 4 (Outer)</td>
<td>1</td>
</tr>
<tr>
<td>43</td>
<td>Fayette</td>
<td>Lexington</td>
<td>KY 1974 (Tates Creek)</td>
<td>Gainesway</td>
<td>1</td>
</tr>
<tr>
<td>44</td>
<td>Fayette</td>
<td>Lexington</td>
<td>KY 1974 (Tates Creek)</td>
<td>KY 4 (Outer)</td>
<td>1</td>
</tr>
<tr>
<td>45</td>
<td>Fayette</td>
<td>Lexington</td>
<td>KY 1974 (Tates Creek)</td>
<td>KY 4 (Inner)</td>
<td>1</td>
</tr>
<tr>
<td>No.</td>
<td>County</td>
<td>City</td>
<td>Street or Route</td>
<td>Street or Route</td>
<td>Approaches</td>
</tr>
<tr>
<td>-----</td>
<td>--------</td>
<td>----------</td>
<td>-------------------------</td>
<td>-------------------------</td>
<td>------------</td>
</tr>
<tr>
<td>46</td>
<td>Fayette</td>
<td>Lexington</td>
<td>KY 1974</td>
<td>Cooper</td>
<td>4</td>
</tr>
<tr>
<td>47</td>
<td>Fayette</td>
<td>Lexington</td>
<td>Lansdowne Rd</td>
<td>Redding Rd</td>
<td>1</td>
</tr>
<tr>
<td>48</td>
<td>Fayette</td>
<td>Lexington</td>
<td>Clays Mill</td>
<td>Wellington Way</td>
<td>1</td>
</tr>
<tr>
<td>49</td>
<td>Fayette</td>
<td>Lexington</td>
<td>US 68 (Harrodsburg Rd)</td>
<td>Lane Allen</td>
<td>2</td>
</tr>
<tr>
<td>50</td>
<td>Fayette</td>
<td>Lexington</td>
<td>US 68 (Harrodsburg Rd)</td>
<td>Larkspur</td>
<td>1</td>
</tr>
<tr>
<td>51</td>
<td>Fayette</td>
<td>Lexington</td>
<td>US 68 (Harrodsburg Rd)</td>
<td>KY 4 (Inner)</td>
<td>1</td>
</tr>
<tr>
<td>52</td>
<td>Fayette</td>
<td>Lexington</td>
<td>US 68 (Harrodsburg Rd)</td>
<td>KY 4 (Outer)</td>
<td>1</td>
</tr>
<tr>
<td>53</td>
<td>Fayette</td>
<td>Lexington</td>
<td>Rose St</td>
<td>Washington Ave</td>
<td>1</td>
</tr>
<tr>
<td>54</td>
<td>Fayette</td>
<td>Lexington</td>
<td>Rose St</td>
<td>Columbia Ave</td>
<td>1</td>
</tr>
<tr>
<td>55</td>
<td>Fayette</td>
<td>Lexington</td>
<td>Reynolds Rd</td>
<td>Fayette Mall Ent</td>
<td>1</td>
</tr>
<tr>
<td>56</td>
<td>Fayette</td>
<td>Lexington</td>
<td>Alumni Drive</td>
<td>KY 4 (Outer)</td>
<td>1</td>
</tr>
<tr>
<td>57</td>
<td>Fayette</td>
<td>Lexington</td>
<td>Alumni Drive</td>
<td>KY 4 (Inner)</td>
<td>1</td>
</tr>
<tr>
<td>58</td>
<td>Jefferson</td>
<td>Louisville</td>
<td>KY 146 (LaGrange Rd)</td>
<td>KY 2050 (Lyndon Ln)</td>
<td>1</td>
</tr>
<tr>
<td>CATEGORY</td>
<td>VARIABLE</td>
<td>NUMBER OF APPROACHES</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>---------------------------------------</td>
<td>-----------------------------------</td>
<td>----------------------</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Speed Limit (mph)</td>
<td>35 or Less</td>
<td>39</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>40 - 45</td>
<td>22</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Over 45</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>85th Percentile Speed (mph)</td>
<td>35 or Less</td>
<td>20</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>36 - 45</td>
<td>38</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Over 45</td>
<td>7</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average Speed (mph)</td>
<td>35 or Less</td>
<td>42</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>36 - 45</td>
<td>21</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Over 45</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sight Distance (feet)</td>
<td>Under 250</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>250 - 500</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>501 - 750</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>751 - 1,000</td>
<td>15</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Over 1,000</td>
<td>29</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sight Time (seconds)</td>
<td>5 or Less</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>6 - 10</td>
<td>11</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>11 - 15</td>
<td>14</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>16 - 20</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Over 20</td>
<td>29</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Left-Turn Signal Configuration</td>
<td>s</td>
<td>50</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>m</td>
<td>9</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>g</td>
<td>6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Left-Turn Signal Head Location</td>
<td>Line between Left-Turn and Adjacent Through Lane</td>
<td>38</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Middle of Left-Turn Lane</td>
<td>27</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Left-Turn Phasing</td>
<td>Leading</td>
<td>52</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Lagging</td>
<td>12</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Other</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of Other Lanes</td>
<td>1</td>
<td>39</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>26</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of Opposing Lanes</td>
<td>1</td>
<td>23</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>42</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of Signal Heads</td>
<td>2</td>
<td>55</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sign</td>
<td>Yes</td>
<td>31</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>34</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Separate Left-Turn Lane</td>
<td>Yes</td>
<td>46</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>19</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
TABLE 2. CHARACTERISTICS OF PERMISSIVE PHASING LOCATIONS (CONTINUED)

<table>
<thead>
<tr>
<th>CATEGORY</th>
<th>VARIABLE</th>
<th>NUMBER OF APPROACHES</th>
</tr>
</thead>
<tbody>
<tr>
<td>History</td>
<td>Part of Original Signal</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td>Installation</td>
<td></td>
</tr>
<tr>
<td></td>
<td>First Left-Turn Signal</td>
<td>28</td>
</tr>
<tr>
<td></td>
<td>Replaced Exclusive Phasing</td>
<td>12</td>
</tr>
<tr>
<td>Control</td>
<td>Actuated</td>
<td>53</td>
</tr>
<tr>
<td></td>
<td>Pre-timed</td>
<td>12</td>
</tr>
<tr>
<td>Coordinated</td>
<td>Yes</td>
<td>33</td>
</tr>
<tr>
<td>System</td>
<td>No</td>
<td>32</td>
</tr>
<tr>
<td>Average Daily Traffic</td>
<td>5,000 - 9,999</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>10,000 - 20,000</td>
<td>24</td>
</tr>
<tr>
<td></td>
<td>Over 20,000</td>
<td>23</td>
</tr>
<tr>
<td></td>
<td>Unknown</td>
<td>9</td>
</tr>
<tr>
<td>Year Installed</td>
<td>Before 1977</td>
<td>19</td>
</tr>
<tr>
<td></td>
<td>1977</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>1978</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>1979</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>1980</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>1981</td>
<td>11</td>
</tr>
<tr>
<td></td>
<td>1982</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>1983</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td>1984</td>
<td>5</td>
</tr>
</tbody>
</table>

* The protected portion of the phase was leading.
### TABLE 3. SUMMARY OF ACCIDENT DATA BEFORE AND AFTER INSTALLATION OF PERMISSIVE PHASING

<table>
<thead>
<tr>
<th>VARIABLE</th>
<th>CATEGORY</th>
<th>NUMBER OF APPROACHES</th>
<th>AVERAGE LEFT-TURN ACCIDENTS PER YEAR</th>
<th>AVERAGE TOTAL ACCIDENTS PER YEAR</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>BEFORE</td>
<td>AFTER</td>
</tr>
<tr>
<td>All</td>
<td>All</td>
<td>44</td>
<td>1.1</td>
<td>2.1</td>
</tr>
<tr>
<td>History</td>
<td>New Signal</td>
<td>9</td>
<td>0.7</td>
<td>1.2</td>
</tr>
<tr>
<td></td>
<td>First Left-Turn Signal</td>
<td>24</td>
<td>1.4</td>
<td>1.3</td>
</tr>
<tr>
<td></td>
<td>Replaced Exclusive</td>
<td>11</td>
<td>1.0</td>
<td>4.6</td>
</tr>
<tr>
<td>Speed Limit</td>
<td>35 mph or Less</td>
<td>25</td>
<td>1.1</td>
<td>1.0</td>
</tr>
<tr>
<td></td>
<td>40-45 mph</td>
<td>15</td>
<td>1.4</td>
<td>3.4</td>
</tr>
<tr>
<td></td>
<td>More than 45 mph</td>
<td>4</td>
<td>0.4</td>
<td>3.8</td>
</tr>
<tr>
<td>Average Speed</td>
<td>35 mph or Less</td>
<td>27</td>
<td>0.9</td>
<td>1.7</td>
</tr>
<tr>
<td></td>
<td>36 - 45 mph</td>
<td>15</td>
<td>1.6</td>
<td>3.0</td>
</tr>
<tr>
<td></td>
<td>More than 45 mph</td>
<td>2</td>
<td>0.4</td>
<td>0.8</td>
</tr>
<tr>
<td>85th Percentile Speed</td>
<td>35 mph or Less</td>
<td>14</td>
<td>0.5</td>
<td>0.6</td>
</tr>
<tr>
<td></td>
<td>36 - 45 mph</td>
<td>23</td>
<td>1.4</td>
<td>2.6</td>
</tr>
<tr>
<td></td>
<td>More than 45 mph</td>
<td>7</td>
<td>1.6</td>
<td>3.4</td>
</tr>
<tr>
<td>Combination of History and Speed Limit</td>
<td>New Signal</td>
<td>35 mph or Less</td>
<td>6</td>
<td>1.0</td>
</tr>
<tr>
<td></td>
<td>40 - 45 mph</td>
<td>1</td>
<td>0.0</td>
<td>1.0</td>
</tr>
<tr>
<td></td>
<td>More than 45 mph</td>
<td>2</td>
<td>0.4</td>
<td>0.8</td>
</tr>
<tr>
<td>First Left-Turn Signal</td>
<td>35 mph or Less</td>
<td>18</td>
<td>1.2</td>
<td>0.9</td>
</tr>
<tr>
<td></td>
<td>40 - 45 mph</td>
<td>5</td>
<td>2.3</td>
<td>1.8</td>
</tr>
<tr>
<td></td>
<td>More than 45 mph</td>
<td>1</td>
<td>0.0</td>
<td>4.7</td>
</tr>
<tr>
<td>Replaced Exclusive</td>
<td>35 mph or Less</td>
<td>1</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td>40 - 45 mph</td>
<td>9</td>
<td>1.1</td>
<td>4.6</td>
</tr>
<tr>
<td></td>
<td>More than 45 mph</td>
<td>1</td>
<td>1.0</td>
<td>8.7</td>
</tr>
<tr>
<td>Sight Distance</td>
<td>Less than 500 feet</td>
<td>7</td>
<td>1.0</td>
<td>1.4</td>
</tr>
<tr>
<td></td>
<td>500 - 1,000 feet</td>
<td>18</td>
<td>1.0</td>
<td>1.7</td>
</tr>
<tr>
<td></td>
<td>Over 1,000 feet</td>
<td>19</td>
<td>1.3</td>
<td>2.7</td>
</tr>
</tbody>
</table>

23
### TABLE 4. SUMMARY OF BEFORE AND AFTER DATA AT "NEW SIGNAL" OR "FIRST LEFT-TURN SIGNAL" LOCATIONS WITH SPEED LIMIT 45 MPH OR LESS

<table>
<thead>
<tr>
<th>VARIABLE</th>
<th>CATEGORY</th>
<th>NUMBER OF APPROACHES</th>
<th>AVERAGE LEFT-TURN ACCIDENTS PER YEAR</th>
<th>AVERAGE TOTAL ACCIDENTS PER YEAR</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>BEFORE</td>
<td>AFTER</td>
</tr>
<tr>
<td>All</td>
<td>All</td>
<td>30</td>
<td>1.3</td>
<td>1.2</td>
</tr>
<tr>
<td>Sign</td>
<td>Yes</td>
<td>17</td>
<td>1.2</td>
<td>1.4</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>13</td>
<td>1.4</td>
<td>0.9</td>
</tr>
<tr>
<td>Signal Head Position</td>
<td>Between Left-Turn and Adjacent Thru Lanes</td>
<td>18</td>
<td>1.0</td>
<td>0.8</td>
</tr>
<tr>
<td></td>
<td>Middle of Left-Turn Lane</td>
<td>12</td>
<td>1.8</td>
<td>1.8</td>
</tr>
<tr>
<td>Number of Signal Heads</td>
<td>Two</td>
<td>23</td>
<td>1.6</td>
<td>1.3</td>
</tr>
<tr>
<td></td>
<td>Three</td>
<td>7</td>
<td>0.5</td>
<td>0.9</td>
</tr>
<tr>
<td>Signal Head Configurations</td>
<td>s</td>
<td>23</td>
<td>1.5</td>
<td>1.2</td>
</tr>
<tr>
<td></td>
<td>m</td>
<td>6</td>
<td>0.8</td>
<td>1.2</td>
</tr>
<tr>
<td></td>
<td>g</td>
<td>1</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Separate Left-Turn Lane</td>
<td>Yes</td>
<td>22</td>
<td>0.7</td>
<td>1.0</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>8</td>
<td>2.9</td>
<td>2.6</td>
</tr>
<tr>
<td>Number of Opposing Lanes</td>
<td>One</td>
<td>16</td>
<td>0.8</td>
<td>1.0</td>
</tr>
<tr>
<td></td>
<td>Two</td>
<td>14</td>
<td>1.9</td>
<td>1.4</td>
</tr>
<tr>
<td>Peak Hour Volume Product**</td>
<td>Under 100,000</td>
<td>5</td>
<td>1.3</td>
<td>0.7</td>
</tr>
<tr>
<td></td>
<td>(Two Opposing Lanes)</td>
<td>100,000 or Above</td>
<td>5</td>
<td>1.9</td>
</tr>
</tbody>
</table>

* All protected portions of the phase were leading.
** Product of left-turn and opposing volumes.
Data limited this analysis to 10 approaches.
<table>
<thead>
<tr>
<th>CATEGORY</th>
<th>VARIABLE</th>
<th>NUMBER OF APPROACHES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Left-Turn Accidents Per Year</td>
<td>Less than 1.0</td>
<td>21</td>
</tr>
<tr>
<td>Per Approach</td>
<td>1.0 - 2.0</td>
<td>18</td>
</tr>
<tr>
<td></td>
<td>2.1 - 3.0</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>3.1 - 4.0</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>4.1 - 5.0</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>Over 5.0</td>
<td>4</td>
</tr>
<tr>
<td>Highest Number of Left-Turn Accidents in Any One Year</td>
<td>0</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Over 10</td>
<td>4</td>
</tr>
<tr>
<td>VARIABLE</td>
<td>CATEGORY</td>
<td>RELATED LEFT-TURN</td>
</tr>
<tr>
<td>--------------------------</td>
<td>-----------------------------------</td>
<td>-------------------</td>
</tr>
<tr>
<td>Severity</td>
<td>Fatality</td>
<td>0.2</td>
</tr>
<tr>
<td>(Most Severe Injury)</td>
<td>Incapacitating Injury</td>
<td>10.3</td>
</tr>
<tr>
<td></td>
<td>Non-Incapacitating Injury</td>
<td>14.9</td>
</tr>
<tr>
<td></td>
<td>Possible Injury</td>
<td>11.8</td>
</tr>
<tr>
<td></td>
<td>Injury - Extent Unknown</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td>Property Damage Only</td>
<td>62.9</td>
</tr>
<tr>
<td>Time of Day</td>
<td>Midnight - 2:59 a.m.</td>
<td>8.5</td>
</tr>
<tr>
<td></td>
<td>3:00 a.m. - 5:59 a.m.</td>
<td>1.4</td>
</tr>
<tr>
<td></td>
<td>6:00 a.m. - 8:59 a.m.</td>
<td>8.5</td>
</tr>
<tr>
<td></td>
<td>9:00 a.m. - 11:59 a.m.</td>
<td>9.9</td>
</tr>
<tr>
<td></td>
<td>Noon - 2:59 p.m.</td>
<td>18.3</td>
</tr>
<tr>
<td></td>
<td>3:00 p.m. - 5:59 p.m.</td>
<td>19.6</td>
</tr>
<tr>
<td></td>
<td>6:00 p.m. - 8:59 p.m.</td>
<td>17.5</td>
</tr>
<tr>
<td></td>
<td>9:00 p.m. - 11:59 p.m.</td>
<td>16.3</td>
</tr>
<tr>
<td>Light Conditions</td>
<td>Daylight</td>
<td>60.0</td>
</tr>
<tr>
<td></td>
<td>Dawn - Dusk</td>
<td>3.5</td>
</tr>
<tr>
<td></td>
<td>Darkness, No Lights</td>
<td>2.7</td>
</tr>
<tr>
<td></td>
<td>Darkness, Lighted</td>
<td>33.8</td>
</tr>
<tr>
<td>Road Surface</td>
<td>Dry</td>
<td>77.2</td>
</tr>
<tr>
<td>Condition</td>
<td>Wet</td>
<td>21.8</td>
</tr>
<tr>
<td></td>
<td>Ice-Snow</td>
<td>1.0</td>
</tr>
<tr>
<td>Month</td>
<td>January</td>
<td>5.4</td>
</tr>
<tr>
<td></td>
<td>February</td>
<td>8.9</td>
</tr>
<tr>
<td></td>
<td>March</td>
<td>7.6</td>
</tr>
<tr>
<td></td>
<td>April</td>
<td>9.1</td>
</tr>
<tr>
<td></td>
<td>May</td>
<td>7.8</td>
</tr>
<tr>
<td></td>
<td>June</td>
<td>7.9</td>
</tr>
<tr>
<td></td>
<td>July</td>
<td>6.4</td>
</tr>
<tr>
<td></td>
<td>August</td>
<td>8.1</td>
</tr>
<tr>
<td></td>
<td>September</td>
<td>10.0</td>
</tr>
<tr>
<td></td>
<td>October</td>
<td>11.8</td>
</tr>
<tr>
<td></td>
<td>November</td>
<td>8.3</td>
</tr>
<tr>
<td></td>
<td>December</td>
<td>8.5</td>
</tr>
<tr>
<td>Day of Week</td>
<td>Sunday</td>
<td>6.6</td>
</tr>
<tr>
<td></td>
<td>Monday</td>
<td>17.1</td>
</tr>
<tr>
<td></td>
<td>Tuesday</td>
<td>13.0</td>
</tr>
<tr>
<td></td>
<td>Wednesday</td>
<td>11.6</td>
</tr>
<tr>
<td></td>
<td>Thursday</td>
<td>18.4</td>
</tr>
<tr>
<td></td>
<td>Friday</td>
<td>19.0</td>
</tr>
<tr>
<td></td>
<td>Saturday</td>
<td>14.3</td>
</tr>
</tbody>
</table>
TABLE 6. CHARACTERISTICS OF RELATED LEFT-TURN ACCIDENTS COMPARED TO STATEWIDE ACCIDENTS (CONTINUED)

<table>
<thead>
<tr>
<th>VARIABLE</th>
<th>CATEGORY</th>
<th>RELATED LEFT-TURN</th>
<th>STATEWIDE (1984)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Driver's Age</td>
<td>16 - 19</td>
<td>15.8</td>
<td>14.6</td>
</tr>
<tr>
<td></td>
<td>20 - 24</td>
<td>15.8</td>
<td>18.7</td>
</tr>
<tr>
<td></td>
<td>25 - 34</td>
<td>25.9</td>
<td>26.5</td>
</tr>
<tr>
<td></td>
<td>35 - 44</td>
<td>12.8</td>
<td>15.9</td>
</tr>
<tr>
<td></td>
<td>45 - 54</td>
<td>10.4</td>
<td>9.4</td>
</tr>
<tr>
<td></td>
<td>55 - 64</td>
<td>9.0</td>
<td>7.6</td>
</tr>
<tr>
<td></td>
<td>65 or Above</td>
<td>10.2</td>
<td>7.3</td>
</tr>
<tr>
<td>Driver's Sex</td>
<td>Male</td>
<td>48.8</td>
<td>64.7</td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>51.2</td>
<td>35.3</td>
</tr>
</tbody>
</table>