Research Report
KTC-95-23

GUIDELINES FOR THE INSTALLATION OF LEFT-TURN PHASING

by

Kenneth R. Agent
Research Engineer

and

Nikiforos Stamatiadis
Assistant Professor

and

Bryan Dyer
Research Assistant

Kentucky Transportation Center
College of Engineering
University of Kentucky
Lexington, Kentucky

in cooperation with

Kentucky Transportation Cabinet
Commonwealth of Kentucky

December 1995

Technical Report Documentation Page

1. Report No. KTC-95-23	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Guidelines for the Installation of Left-Turn Phasing		5. Report Date December 1995
		6. Performing Organization Code
7. Author(s) K. R. Agent; Nikiforos Stamatiadis; and Bryan Dyer		8. Performing Organization Report No. KTC-95-23
9. Performing Organization Name and Address Kentucky Transportation Center College of Engineering University of Kentucky Lexington, KY 40506-0281		10. Work Unit No. (TRAIS)
		11. Contract or Grant No.
		13. Type of Report and Period Covered Final
12. Sponsoring Agency Name and Address Kentucky Transportation Cabinet State Office Building Frankfort, KY 40622		14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

The objective of this study was to update the guidelines to be considered when determining whether left-turn phasing should be used and the appropriate type of phasing to use. Emphasis was placed on high speed areas.

There were 264 intersections included in the study with data obtained for 518 approaches at these intersections. The data included accidents and characteristics of the intersection. Traffic conflict data were collected. Simulation models were used to estimate delays.

Recommendations were made concerning guidelines to consider when deciding whether to install left turn phasing and whether to use protected-only or protected/permitted phasing. Variables considered included accident history, traffic volume and delay, traffic speed, number of left-turn lanes, number of opposing lanes, sight distance, intersection geometrics, left-turn volume, and opposing volume.

17. Key Words left turn, delay traffic signal, conflict accidents volume	18. Distribution Statement Unlimited with approval of Kentucky Transportation Cabinet

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	100	

Form DOT 1700.7 (8-72)   Reproduction of completed page authorized

TABLE OF CONTENTS

INTRODUCTION

Past research has resulted in the development of guidelines for the installation of left turn phasing and for the use of protected/permitted left- turn phasing (1,2,3). Decisions concerning left-turn phasing are influenced by such factors as delays, accidents, traffic volume, speeds, and geometry of the intersection.

The issue of left-turn phasing is a two-step process. The first question is whether a separate left-turn phase is warranted. Major factors affecting this decision are left-turn volumes, opposing volumes, left-turn delays, and left-turn accidents. After a decision has been made to add a left-turn phase, one of two basic alternative phasing methods is commonly used. Until the mid 1980's, the predominant type of left-turn phasing was a protected-only type in which the left-turn driver is allowed to turn left only during a green arrow portion of the cycle, during which opposing traffic is stopped. An alternative type of phasing that has received increased usage in recent years involves a combination of protected and permitted left-turn movements. This type of phasing is termed protected/permitted or permitted/protected depending on the phasing sequence. 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 when there are available gaps in opposing traffic. This is the permitted portion of the phase. Split phasing also is used in some instances.

Specific warrants have been developed for use as guidelines when considering the addition of separate left-turn phasing (1). These warrants consider accident experience, delay, volumes, and traffic conflicts. The next research in this area involved a comparison of protected only and the combination of protected and permitted phasing (P/P phasing) (2). It was found that left-turn and total intersection delays decreased when protected-only phasing was replaced with P/P left-turn phasing.

P/P phasing has been shown to be popular to drivers. Research has shown there are typically increases in left-turn accidents when protected-only phasing is replaced by P/P phasing, especially in the first months following the change. Other types of accidents at intersection will typically decrease.

The objective of this study was to update the guidelines to be considered when determining whether left-turn phasing should be used and the appropriate type of phasing to use. Emphasis was placed on high speed areas.

PROCEDURE

Review of Literature

A review of the available literature was conducted concerning the issues of guidelines for determining both when left-turn phasing should be used and the appropriate type of phasing to use. A total of 50 references are included in the review of literature. Summaries of the information obtained from the various references are given in Appendix A.

Intersection Sample

A broad sample of intersections was chosen for investigation. This was done to allow a comparison of the types of left-turn phasing and produce a set of guidelines which would be compatable for any type of intersection. Intersections were chosen to obtain a sample of various types of phasing at locations with different speed limits. The three types of left-turn phasing which were investigated were protected-only, P/P, and permissive.

Speed limit was a major consideration. Emphasis was placed on including a large number of intersections where the speed limit was 45 mph or above. A representative sample of intersections was obtained. It was not possible to include all signalized intersections across the state at high-speed locations or all intersections with P/P phasing in the analysis. Intersections where signals were installed since the start of the accident data in 1991 or where the left-turn phasing was changed since that date were not included.

Several methods were used to identify intersections. Computer summaries were obtained listing accidents occurring at intersections with a traffic signal or at intersections where the speed limit was 45 mph or above. A letter was sent to traffic engineers in the various Department of Highways districts for suggestions for intersections to include in the study.

Intersection Characteristics

After the sample of intersections was determined, various characteristics were determined for use in the analysis. The data were obtained for the approaches to be included. All of the analysis were conducted by approach. At some intersections, data were included for all four approaches while only one approach was used at other locations.

The type of left-turn phasing was obtained as well as whether the phasing had been changed in the past few years. The phasing used in the analysis is the type in existence over the time period when accident data were summarized. In a few instances, a recent change has been made such that the existing phasing is not that shown for an intersection. Whether a left- turn lane was present on an approach was determined. The number of opposing lanes was also used in the analysis. The speed limit was determined. Other information included whether there was a related regulatory sign, the type of signal head arrangement, and whether the protected portion of the phase was leading or lagging.

When available, traffic volume information was obtained. In some cases, no turning movement counts had been taken at an intersection so this information could not be included for those intersections. Hourly left-turn and opposing traffic volumes were necessary to calculate left-turn accident rates. The hourly counts were typically taken when the original signal was installed so, in some instances, the counts were several years old. The counts were not used if it was felt that they were so old that they were not accurate. Hourly volumes were also collected as part of the conflict data collection procedure.

The information was obtained so the left-turn phasing and other related characteristics of the intersection could be related to the accident history at the intersection. As previouly noted, protected-only phasing allows left-turning vehicles to turn only on a green arrow while opposing traffic is stopped. In general, protected-only phasing is accompanied by an exclusive left-turn lane and a separate signal head type "c" as described in the Manual on Uniform Traffic Control Devices (MUTCD) (4). There is no separate left- turn indication at permissive only locations, and a separate left-turn lane may not be provided. There is typically a separate left-turn lane at P/P intersections. Either signal head arrangements "s" or "m" (as described in the MUTCD) are used with P/P phasing. This signal head is usually placed between the left-turn lane and adjacent through lane. In some instances, a regulatory sign (R10-12 in the MUTCD) is added to remind drivers to yield on the green ball.

Accident Analysis

The accident analysis data for the intersections included accidents for a four-year period (1991 through 1994) at 251 intersections and for a three-year period (1992 through 1994) at 13 intersections. The intersections with three years of data were off the state maintained road system in Lexington. The total numbers of accidents were also obtained at the intersections with four years of data.

The critical type of accident to be considered in this study is the opposing left-turn accident. An opposing left-turn accident occurs when a driver turns left into the path of the opposing traffic. This type of accident was related to the various intersection characteristics. Since both three and four years of data were used, the average yearly number of left-turn accidents was used. The accidents were summarized by approach.

Traffic Conflicts

Traffic conflicts offer an alternative to traffic accidents as a method of identifying an intersection which has a potential left-turn accident problem. Traffic conflict data were collected at a sample of intersections in Lexington. The intersections were selected to enable a large range in left-turn accidents and traffic volumes. A left-turn conflict occurred when a left-turning vehicle turned in front of an opposing vehicle and brakelights were observed on the opposing vehicle. A secondary conflict occurred when brakelights were observed on a vehicle behind the first opposing vehicle. Conflicts on an approach were related to the number of left-turn accidents on that approach. Conflicts were also related to left-turn and opposing volumes. The percentage of left-turning vehicles which made the left turn on the permissive portion of the phase was also determined as part of the data collection.

Left-Turn Delay

An additional method for determining the type of left-turn phasing is delay. Increased delays at intersections may force drivers to accept shorter gaps in traffic when completing left-turn maneuvers and thus increase the potential of a traffic conflict and subsequently cause an accident. To estimate these delays, and especially left-turn delays, simulation models were utilized. Since most high speed intersections have some type of actuated signal (semi- or fully-actuated), the use of the Highway Capacity Software was not considered adequate to estimate these delays due to intrinsic problems dealing with actuated signals. Therefore, the use of TRAF-NETSIM was considered more appropriate to simulate these traffic conditions. Moreover, TRAF-NETSIM can provide delays for each movement through the intersection and weighted delays for the entire intersection can be computed as well. The delays used in this analysis were for left-turning vehicles.

Models were constructed to represent a variety of combinations of left-turning volumes (50, 100, 150, and 200 vehicles per hour); opposing volumes (ranging from 500 to 1500 vehicles per hour); cross street volumes (400, 700, and 1,000 vehicles per hour); and approach lanes (one or two lane approaches). There was a total of 264 cases considered for each of the three left-turn phasing schemes used (protected-only, permissive only, and protected/permitted). Thus, a total of 792 different cases were simulated. Also, to improve the accuracy of the simulations, a minimum of five different random numbers was selected for the simulation such that at least five estimates were obtained for each case. More than five estimates were obtained for cases where a large variation among the delay values were observed. This occurred in only a very few cases (approximately 10 cases). To generate an observation for each case, the average delay of all observations was computed.

RESULTS

Inventory

There were 264 intersections included in this study with data obtained for 518 approaches at these intersections. The intersections were scattered across the state with approaches included in 52 counties. The largest number of intersections (78) was in Fayette County. A listing of the intersections is given in Table 1. For each intersection, the county, intersection number, major route and its milepoint, and intersecting route or street are given. The data obtained for each intersection, which were used in the analysis, are given in Appendix B. The intersection numbers given in Table 1 can be used to identify the corresponding intersection in Appendix B. This information includes the number of left-turn accidents, speed limit, number of left-turn lanes, number of opposing through lanes, peak hour opposing through volume, peak hour left-turn volume, type of phasing, whether the left-turn phasing is leading or lagging, whether there is a regulatory sign, and the signal head configuration.

The number of approaches included at any intersection varied from one to four. Only one approach was included for a "T" intersection while all four approaches were included for some of the intersections of two major routes. These approaches were chosen to represent the three types of left-turn phasing at locations with varying speed limits. Several intersections originally identified were omitted from the analysis because some of the necessary information could not be obtained. For example, when only one or two total accidents were identified over the four-year period, the assumption was made that there was a problem with the milepoint identification at that intersection and it was omitted from the analysis. Information for these intersections was gathered through a combination of field inspections, a survey sent to local Department of Highways district offices, and information provided by the Lexington Fayette Urban County Government.

Some of the significant characteristics of these locations are summarized in Table 2. Given the emphasis on high speed locations, the largest number of approaches (41 percent) had a speed limit of over 45 mph. The speed limit for all but a few of these high-speed approaches was 55 mph. This was the speed limit on the approach opposing the left-turn movement.

Considering all approaches, there was an even distribution between types of left-turn phasing. For the approaches with a speed limit of over 45 mph, there was a relatively even distribution between protected-only and permissive phasing. Only four P/P approaches had an opposing speed limit over 45 mph, and none of these approaches had a high number of left-turn accidents. The highest number of accidents was five in three years with the others having four in four years, one in three years, and none in four years.

Almost all of the left-turn phasing was leading (96 percent) where the protected left-turn arrow was displayed before the through traffic was allowed to proceed on the green ball indication. All of the protected-only phasing locations used the lens arrangement "c" given in the MUTCD. Almost all of the P/P locations used lens arrangement "s" (96 percent) with the remaining using the "m" arrangement. The "s" configuration is a five-section head with the "m" arrangement a vertical alignment.

The large majority of the approaches (87 percent) had one left-turn lane. There were only eight approaches with two left-turn lanes. Of the eight approaches, seven had protected-only phasing. There was one P/P phasing approach which allowed left turns from two lanes, and there was a high number of left-turn accidents at this location (26 in four years).

The majority of the left turns (64 percent) had to cross two opposing through lanes. Only four had three opposing lanes. Of those four approaches, two had protected-only phasing and two had P/P phasing. At the two P/P approaches, there were three and six accidents in a four-year period. The phasing at the approach with six accidents has been changed to protected-only phasing. The speed limit at those locations was 45 mph.

A regulatory sign was not typically used on the approaches. Such a sign was present at 24 percent of P/P approaches and nine percent of permissive approaches.

Accident Analysis

A distribution of the average number of left-turn accidents per approach is given in Table 3. Considering all approaches, 69 percent had an average of 0.5 left-turn accidents per year or less. This percentage was 93 percent for protected-only phasing locations compared to 40 percent for P/P phasing and 71 percent for permissive phasing approaches. Only eight percent had an average over two accidents per year with no protected-only approaches having this number of accidents. This percentage was 18 percent for P/P phasing and 7 percent for permissive phasing approaches.

The intersection approaches having the highest average number of left- turn accidents were identified. The approach with the highest number (13 left-turn accidents per year) was Alumni Drive at the KY 4 outer loop entrance ramp in Lexington. This is a four-lane roadway with a speed limit of 45 mph and P/P phasing. A review of the accident reports showed that the majority of collisions occurred during high volume conditions when traffic was backed up and a driver in the left, opposing through lane allowed the left- turning driver to turn in front of him and a collision occurred with a vehicle in the right, opposing lane. The view of the left-turning driver to observe the approaching vehicle in the right, through lane was restricted by traffic stopped in the left, through lane.

The intersection with the second highest number of left-turn accidents was the northbound approach of Man O War Boulevard to Alumni Drive in Lexington with 7.0 left-turn accidents per year. This is a four-lane roadway with a speed limit of 45 mph and P/P phasing. The accident reports noted that, in many instances, the collision occurred when a left-turning vehicle attempted to complete the left turn after the signal indication changed to yellow and the opposing vehicle continued through the intersection during the yellow.

An average of 6.5 left-turn accidents per year occurred at the northbound approach of Rose Street turning onto Main Street in Lexington as well as the inbound approach on Richmond Road at Man O War Boulevard in Lexington. The outbound approach on Richmond Road at this intersection had 5.0 left-turn accidents per year. The northbound approach on Rose Street is unique in that it has P/P phasing, and left turns can be made from two lanes. This was the only approach found that had P/P phasing with left turns allowed from two lanes. The right, left-turn lane is a shared through and left- turn lane. The accident reports typically did not indicate the lane used by the left-turning vehicle. At Man O War Boulevard, Richmond Road is a four-lane roadway with a speed limit of 45 mph and P/P phasing. Review of the accident reports revealed that several collisions occurred when both the left- turning and through vehicles entered the intersection during the yellow indication. The notation was made on several reports that the left-turning driver did not observe the approaching through vehicle.

As shown in Table 4, left-turn accidents are a severe type of accident compared to all intersection accidents. About 40 percent of left-turn accidents involved an injury compared to 29 percent of all intersection accidents.

Accident reports involving a left-turning vehicle were obtained for the past three- to four-year period and summarized by approach (Table 5) considering speed limit and type of phasing. The data given in this table are for locations where volume data were found such that rates could be calculated. Volume data were obtained at 408 approaches. The average number of left-turn accidents per approach per year at these locations was 0.69. The average was only 0.20 left-turn accidents per approach per year for approaches with protected-only phasing and increased to 1.32 for P/P phasing and 0.50 for permissive approaches. These averages were almost identical to the average for all 518 approaches (0.20 for protected-only, 1.33 for P/P, and 0.58 for permissive). This shows the sample of approaches with volume data was representative of all approaches.

For all approaches without protected-only phasing, with volume data, there was an average of 0.91 left-turn accidents per year per approach (0.96 for all such approaches). This was almost identical to that found in the previous report where warrants were developed for left-turn phasing (1). This results in a critical number of left- turn accidents per approach (for a level of statistical significance of 0.995) of four in one year, six in two years, or eight in three years.

The lower number of left-turn accidents per year per approach at permissive, compared to P/P approaches, would be related to the lower traffic volumes at the permissive approaches. The average peak hour left-turn volume at the permissive locations was only 68 compared to 152 at the P/P approaches. The P/P locations had higher average peak hour volumes (both left turn and opposing) than the protected-only locations.

Peak hour volumes were used as a method of exposure. A low accident rate, compared to P/P and permissive locations, was found for protected-only approaches when left-turn and opposing volumes were considered. The comparison between P/P and permissive approaches changed when volumes were considered along with the number of accidents. Considering only left- turn volume or the sum of left-turn and opposing volume, the rate at P/P locations was slightly higher than permissive approaches. However, when the product of left-turn and opposing volumes was considered, the rate at permissive approaches was higher than at P/P approaches. The rate at P/P approaches was generally closer to the permissive approaches than the protected-only approaches.

The pattern found when all approaches were considered continued when the analysis was performed by speed limit. When the rate was calculated using the product of left-turn and opposing traffic as the measure of exposure, protected-only approaches generally had the lowest rates with the rates for P/P approaches lower than for permissive approaches. There was no pattern of a consistent increase in accident rates as speed limit increased. Past research had indicated the use of P/P phasing should be restricted at high speed limits, and there were only four P/P approaches with a speed limit of 50 to 55 mph. The rate at these limited number of approaches did not indicate an accident problem. This shows that factors in addition to speed limit, such as accident history and number of opposing lanes, must be considered when determining the proper type of phasing to install.

The data in Table 5 allow a comparison of accident rates by speed limit for permissive phasing locations. There was a large sample of permissive approaches where the speed limit was over 45 mph. The accident statistics do not show a problem at the high speed locations compared with those where the speed limit was 35 mph or less. The higher speed locations with permissive phasing had a lower left-turn volume than the 35 mph speed limit locations. The data support the conclusion that speed limit, by itself, does not warrant the installation of a left-turn phase.

The number of opposing lanes was also considered in Table 6. Given the limited number of approaches with three opposing lanes, either one or two opposing lanes was used in this analysis. Considering all the combinations, no definite pattern was evident when relating rates to one or two opposing lanes. It cannot be stated that the rate for two opposing lanes is consistly higher than for one opposing lane. There was a higher number of left-turn accidents for two opposing lanes compared to one opposing lane but volumes were also higher.

The average rates for P/P locations given in Tables 5 and 6 can be used for a comparison to rates calculated for a given P/P intersection approach. These rates, along with volume counts, can be used to calculate critical rates.

Various characteristics of the intersections were related to the accident data (Table 7). When leading and lagging operation was compared at P/P approaches, the rate for lagging phasing was higher than for leading. The rate for the small number of P/P locations having an "m" signal configuration was lower than for the typical "s" configuration. For protected-only approaches, the rate was higher for two compared to one left-turn lane. There was a very high rate at the one P/P approach where left turns were allowed from two lanes. The rate for P/P approaches with no left turn lane was substantially higher than for one left-turn lane. The rate was slightly higher at P/P approaches with no regulatory sign compared to approaches having a sign while the rates at permissive only approaches with and without the regulatory sign were almost identical.

There was a wide range in accident experience at P/P locations. In an attempt to isolate factors which may contribute to a higher number of accidents, the characteristics at approaches with one or fewer left-turn accidents per year were compared with approaches with one to two or over two accidents per year. A summary of this comparison is shown in Table 8. It can be seen that several variables have an effect on left-turn accidents. There was a higher percentage of approaches with more than two accidents per year for: a speed limit of 40-45 mph compared to 35 mph or less; no left- turn lane or two left-turn lanes compared to one left-turn lane; two opposing lanes compared to one opposing lane; approaches with a peak hour left-turn volume over 300; approaches with an opposing volume of over 1,000 for two opposing lanes; and a product of left-turn and opposing volume of over 300,000 for two opposing lanes and 150,000 for one opposing lane.

Plots of the number of left-turn accidents per year versus left-turn volume, opposing volume, and the product of left-turn and opposing volume were prepared for one and two opposing lanes and for the three types of left- turn phasing (Figures 1 through 6). These plots show the best fit linear relationship. The r-square values show a poor relationship. The best relationships were found using the product of left-turn and opposing traffic, following by left turn volume. Considering type of phasing, the best relationships were found using P/P phasing.

Traffic Conflicts

A summary of the traffic conflict data is given in Table 9. Conflict data were taken at 58 approaches at 29 intersections. Almost all of the intersections were at locations with P/P phasing. An attempt was made to relate left-turn accidents and conflicts.

Several graphs were prepared relating peak hour conflicts to the variables such as accidents and left-turn and opposing volumes. Several types of plots such as linear, power, and exponential were used. The best relationship between left-turn accidents and conflicts was obtained using a linear graph. As shown in Figure 7, the variability of the data resulted in an r-square value of 0.37. Using the equation of the line and the critical value of four left-turn accidents in a year results in a critical number of six left-turn conflicts in a peak hour.

The relationship between conflicts and left-turn volume is shown in Figure 8. Similar relationships were determined for opposing volume (Figure 9) and the product of left-turn and opposing volumes (Figure 10).

Left-Turn Delay

Left-turn delay was determined as a function of type of phasing, opposing volume, left-turn volume, and number of lanes. A description of the results of this analysis is given in Appendix C.

Considering only delays to left-turning traffic, the following points should be considered when determining the appropriate left-turn phase plan: protected-only left-turn phasing will result in high left-turn delays while permitted phasing can reduce these delays; for approaches with one opposing lane, the use of permissive or P/P left-turn phasing will produce similar left- turn delays; for approaches with two opposing lanes, P/P phasing will produce lower delays than permissive; the desired left-turn phasing for both one and two lane approaches is P/P since it produces similar delays as permissive while it provides some level of safety for left-turning vehicles; and protected-only left-turn phasing should be considered only for locations with a high number of left-turn accidents or where is a high left-turn accident potential.

RECOMMENDATIONS

The objectives of this study were to develop guidelines for: 1) when to use left-turn phasing and 2) the type of phasing to use (protected only or protected/permitted (P/P)). Use of left-turn phasing is a two-step process. First, the decision is made concerning whether left turn phasing is warranted. If it is decided that left-turn phasing is warranted, the next decision is whether protected-only or P/P phasing should be used.

The data indicate accident history and traffic volumes or delay are the major areas which can be used to show a need for left-turn phasing. Traffic speed by itself does not indicate a need for left-turn phasing. P/P phasing is the most efficient type to use but it does not solve an accident problem.

Following is a discussion of the factors to consider, along with guidelines for each factor, when deciding when and what type of left-turn phasing is appropriate. When determining whether protected-only or P/P phasing is appropriate, a combination of the factors should be considered. Since P/P phasing results in lower delays, it should be used unless a combination of some of the following factors shows there is an existing left-turn problem or a potential left-turn accident problem may be created.

Accident History

A high number and rate of left-turn accidents indicate a need for left-turn phasing. Protected-only phasing should be considered when the number of left-turn accidents on an approach is four or more in one year, six or more in two years, or eight or more in three years. If this number of left-turn accident occurs, the left-turn accident rate should be compared to the average rates given in Tables 5 and 6, as well as critical rates calculated using the rates given in these tables and volume counts for a given approach. P/P phasing is not appropriate when left-turn phasing is installed as a result of an accident problem.

Traffic Volume and Delay

Left-turn phasing should be considered when the combination of left- turn volume and opposing volume reaches a level which results in excessive delay to left-turning vehicles. When installed as a result of traffic volumes and delay, P/P phasing should be used unless a factor indicating an actual or potential accident problem precludes its use. The product of left-turning and opposing volume has been shown to be the best exposure measure to use. Left-turn phasing should be considered when the hourly product of left-turning and opposing volumes during peak hours exceeds 100,000 on a four-lane street or 50,000 on a two-lane street. There should also be a minimum of two left-turning vehicles per cycle during this time period. When the volume product becomes excessive (over 300,000 on a four-lane street or over 150,000 on a two-lane street), consider the use of protected-only phasing.

Delay could be measured as an alternative to the volume product. Left- turn phasing should be considered if there are 2.0 vehicle-hours of delay on an approach during a peak hour. Data given in Appendix C can also be used in the decision process relating to delay.

Traffic Speed

Left-turn phasing is not always needed at high-speed signalized intersections. Other factors must be used (left-turn accidents or traffic volumes and delay) to indicate the need for separate phasing. If the need for phasing is indicated, P/P phasing would not typically be used at a location where the speed of the opposing traffic is over 45 mph. However, traffic speed by itself should not preclude the use of P/P phasing. All factors must be considered and, if there are no other factors which may indicate a potential problem, P/P phasing could be placed at a 55-mph location. If P/P phasing is placed at a location with an operating speed of over 45 mph, accidents and conflicts should be monitoried.

Number of Left-Turn Lanes

Protected-only phasing should be used when traffic can turn left from more than one lane. The characteristics of an intersection should be studied prior to placing P/P phasing on an approach with no left-turn lane.

Number of Opposing Lanes

Protected-only phasing should typically be used when there are more than two opposing, through lanes. Other factors must be considered. For example, protected/permitted phasing would not be appropriate for an approach where there are three opposing lanes and the operating speed is over 45 mph.

Sight Distance

Protected-only phasing should be used if there is a sight distance problem. The minimum necessary sight distance, as given in "A Policy on Geometric Design of Highways and Streets", would be 250 feet at 35 mph, 400 feet at 45 mph, and 550 feet at 55 mph (5).

Intersection Geometrics

Protected-only phasing should be used if the intersection geometrics result in the necessity of placing a separate signal head for the left-turn lane.

Left-Turn Volume

If the hourly left-turn volume is routinely over 300, consider the use of protected-only phasing. If there is a large number of heavy trucks making the left turn, along with a high left-turn volume, protected-only phasing should be strongly considered.

Opposing Volume

If the hourly opposing volume becomes excessive (750 for one opposing lane or 1,500 for two opposing lanes), and there is substantial left turn volume, consider protected-only phasing.

Traffic Conflicts

Consider protected-only phasing if there is a consistent average of at least six left-turn conflicts per hour on an approach.

The following guidelines should be used relating to the installation of P/P phasing.

1. A regulatory sign would not typically be necessary. Such a sign (R10-12 in the MUTCD) should only be used when a potential accident problem may exist.

2. Considering accident potential, leading phasing is the preferred phasing to be used with P/P phasing. Lens arrangement "s" in the MUTCD should be used with leading phasing. Lagging phasing may be considered as a method to increase intersection efficiency when there are no indicators of a possible accident problem.

3. When using P/P phasing, the signal head for the left-turn movement should be located on the line separating the left-turn lane and the near, through lane. Left-turning traffic should not have a separate signal head.

REFERENCES

1. Agent, K.R., "Development of Warrants for Left-Turn Phasing," Kentucky Department of Transportation, Research Report 456, August 1976.

2. Agent, K.R., "An Evaluation of Permissive Left-Turn Phasing," Kentucky Department of Transportation, Research Report 519, April 1979.

3. Agent, K.R., "Guidelines for the Use of Protected/Permissive Left-Turn Phasing," University of Kentucky, Transportation Research Program, Research Report UKTRP-85-19, August 1985.

4. Manual on Uniform Traffic Control Devices, U.S. Department of Transportation, Federal Highway Administration, 1988.

5. "A Policy on Geometric Design of Highways and Streets," American Association of State Highway and Transportation Officials, 1984.

TABLE 1. LIST OF INTERSECTIONS

COUNTY	INTERSECTION NUMBER	ROUTE	MP	INTERSECTING ROUTE
ALLEN	2.1	US 31E	7.415	KY 100
	2.2	US 31E	8.610	US 231
	2.3	US 31E	10.582	KY 101
ANDERSON	3.1	US 127B	4.017	KY 44
	3.2	US 127B	3.272	US 62
BARREN	5.1	US 31W	6.823	KY 90
	5.2	US 31E	12.840	US 31EB
	5.3	US 31E	13.300	KY 1297
	5.4	US 31E	13.940	Grandview
	5.5	US 31E	14.258	US 68
	5.6	US 31E	14.600	Barren River Plaza
	5.7	US 31E	14.849	KY 90
BELL	7.1	US 25E	12.859	US 119
	7.2	US 25E	3.270	KY 441
BOONE	8.1	KY 18	11.811	KY 237
	8.2	KY 18	12.585	KY 3168
	8.3	US 42	12.656	KY 237
	8.4	US 25	4.889	KY 338
	8.5	KY 20	16.622	KY 237
BOURBON	9.1	US 27	8.313	US 460
BOYD	10.1	US 23	10.563	I-64
	10.2	US 23	10.678	I-64
	10.3	US 60	4.023	KY 180
	10.4	US 23	10.310	Old US 23
	10.5	US 60	6.555	KY 538
	10.6	US 60	7.132	Summit Rd.
	10.7	US 60	8.875	KY 766
	10.8	KY 180	0.927	KY 3291
	10.9	US 60	8.000	KY 716
	10.10	US 60	9.638	KY 1134
BOYLE	11.1	US 127B	3.196	US 150
	11.2	US 127B	1.232	KY 37
	11.3	US 127B	1.802	KY 34
BULLITT	15.1	US 31E	3.185	KY 44

TABLE 1. LIST OF INTERSECTIONS (Continued)

COUNTY	INTERSECTION NUMBER	ROUTE	MP	INTERSECTING ROUTE
CAMPBELL	19.1	US 27	13.686	KY 9
	19.2	US 27	14.940	E. Alex.
	19.3	US 27	15.701	KY 1998
	19.4	US 27	16.276	Johns Hills
	19.5	US 27	18.814	KY 445
	19.6	US 27	19.964	Highland
	19.7	KY 9	17.181	Brighten
CARTER	22.1	US 60	24.129	KY 7
	22.2	KY 7	11.502	I-64
CHRISTIAN	24.1	US 41A	3.967	KY 117
	24.2	US 41	14.786	KY 1682
	24.3	US 41A	14.410	KY 380
	24.4	US 41	11.025	KY 380
	24.5	US 68	10.866	US 41
	24.6	US 41A	1.738	KY 911
	24.7	US 41A	1.429	Gate 6
	24.8	US 41A	0.968	Gate 5
	24.9	US 41A	0.268	Gate 4
	24.10	US 41A	0.004	KY 400
	24.11	US 68	10.137	KY 1007
	24.12	KY 1007	1.358	Glass
	24.13	US 68	9.500	KY 109
DAVIESS	30.1	US 54	4.505	KY 1456
	30.2	US 231	12.067	KY 1432
	30.3	US 431	13.686	Griffith
	30.4	US 431	13.536	18th st.
	30.5	US 231 NB	13.319	18th st.
	30.6	US 231 SB	13.579	18th st.
	30.7	US 60	10.615	KY 331
	30.8	US 60	16.776	KY 144
	30.9	US 431	11.200	Salam
FAYETTE	34.1	US 68	3.110	KY 4
	34.2	US 25	8.244	KY 418
	34.3	US 60	2.442	Keeneland
	34.4	US 60	3.034	Man O' War
	34.5	US 60	11.895	Elkhorn Dr.
	34.6	US 60	12.085	I-75
	34.7	US68	2.376	Ft. Harrod Dr.
	34.8	KY 922	1.850	Griffin Gate
	34.9	KY 922	2.800	Holiday Inn

TABLE 1. LIST OF INTERSECTIONS (Continued)

COUNTY	INTERSECTION NUMBER	ROUTE	MP	INTERSECTING ROUTE
FAYETTE	34.10	KY 922	3.070	Stanton Way
	34.11	US 25	9.198	Squires Rd.
	34.12	US 68	1.625	Man O' War
	34.13	KY 418	2.491	I-75
	34.14	US 25	9.578	Eagle Creek
	34.15	US 25	9.640	Locust Hill
	34.16	US 25	9.698	Man O' War
	34.17	US 25	10.144	Mt Tabor
	34.18	US 25	10.447	Patchen Dr.
	34.19	US 25	10.788	New Circle
	34.20	US 25	10.810	Lexington Mall
	34.21	US 25	12.898	Ashland
	34.22	US 25	13.017	Walton
	34.23	US 25	13.254	Forrest
	34.24	US 25	13.278	Woodland
	34.25	US 25	13.582	Rose
	34.26	US 25	13.762	Martin Luther King
	34.27	US 25	14.437	Jefferson
	34.28	US 25	14.632	Newton
	34.29	US 25	16.157	New Circle
	34.30	US 25	16.280	Mercer
	34.31	US 27	2.908	Stone
	34.32	US 27	3.472	Southland
	34.33	US 27	5.039	Leader
	34.34	US 27	6.200	Maxwell
	34.35	US 27	6.368	High
	34.36	US 27	6.548	Short
	34.37	US 27	7.645	Loudon
	34.38	US 27	9.343	Haggard
	34.39	US 60	5.589	Village
	34.40	US 60	6.105	Oxford
	34.41	US 60	6.975	Forbes
	34.42	US 60	9.541	Loudon
	34.43	US 60	9.922	Industry
	34.44	US 68	2.910	Corporate
	34.45	US 68	3.285	Alexandria
	34.46	US 68	4.288	Lane Allen
	34.47	US 68	5.635	Red Mile
	34.48	US 68	5.933	Angliana
	34.49	US 421	1.042	Forbes
	34.50	US 421	1.402	Boiling Springs
	34.51	KY 353	1.203	Winburn
	34.52	KY 922	0.313	Loudon
	34.53	KY 1974	7.782	Man O' War

TABLE 1. LIST OF INTERSECTIONS (Continued)

COUNTY	INTERSECTION NUMBER	ROUTE	MP	INTERSECTING ROUTE
FAYETTE	34.54	KY 1974	8.085	Wilson Downing
	34.55	KY 1974	8.406	Armstrong Mill
	34.56	KY 1974	8.973	Gainesway
	34.57	KY 1974	9.348	New Circle
	34.58	KY 1974	9.821	Dove Run
	34.59	KY 1974	10.532	Alumni
	34.60	KY 1974	11.487	Cooper
	34.61	KY 1974	12.044	Euclid
	34.62	KY 1974	12.833	Rose
	34.63	KY 1974	12.157	Ashland
	34.64	US 68	3.834	Larkspur
	34.65	KY 922	2.100	Sugar Maple Ln.
	34.66	Clays Mill Rd.	NA	Pasadena Dr.
	34.67	Clays Mill Rd.	NA	Reynolds Rd.
	34.68	Clays Mill Rd.	NA	Wellington Way
	34.69	Man O War Blvd.	NA	Boston Rd.
	34.70	Man O War Blvd.	NA	Todds Rd.
	34.71	Man O War Blvd.	NA	Pimlico Pkwy.
	34.72	Man O War Blvd.	NA	Clays Mill Rd.
	34.73	Man O War Blvd.	NA	Alumni Dr.
	34.74	Man O War Blvd.	NA	Armstrong Mill Rd.
	34.75	Man O War Blvd.	NA	Palumbo Dr.
	34.76	Alumni Dr.	NA	Yellowstone Pkwy.
	34.77	Alumni Dr.	NA	KY 4 inner
	34.78	Alumni Dr.	NA	KY 4 outer
FLEMING	35.1	KY 11	11.884	KY 32
FLOYD	36.1	US 23	0.896	KY 979
	36.2	US 23	10.597	KY 1428
	36.3	KY 80	8.579	KY 122
FRANKLIN	37.1	US 421	3.860	Shenkel Lane
	37.2	KY 676	1.492	KY 420
	37.3	KY 676	3.172	KY 1659
	37.4	US 127	2.224	KY 1665
	37.5	US 60	5.196	KY 2817
	37.6	KY 676	0.512	Collins lane
	37.7	KY 676	0.200	Limestone Dr.
GRAVES	42.1	US 45	20.555	KY 1276
GREENUP	45.1	US 23	1.220	Ashland Dr.
	45.2	US 23	10.249	KY 1

TABLE 1. LIST OF INTERSECTIONS (Continued)

COUNTY	INTERSECTION NUMBER	ROUTE	MP	INTERSECTING ROUTE
GREENUP	45.3	US 23	28.936	KY 10
	45.4	US 23	11.175	KY 2
	45.5	US 23	1.839	KY 244
	45.6	US 23	4.507	KY 750
HANCOCK	46.1	US 60	1.933	KY 657
HARDIN	47.1	US 31W	21.130	Pine Valley Rd.
	47.2	US 31W	14.807	KY 61 W.K. Pkwy
	47.3	US 31W	23.967	KY 434
	47.4	US 31W	24.408	KY 313
	47.5	US 31W	25.800	Blackjack Rd.
	47.6	US 31W	2.118	KY 1357
	47.7	US 31W	27.167	KY 144
	47.8	US 31W	18.170	Diecks
	47.9	US 31W	19.478	KY 3005
	47.10	US 31W	19.800	Town Center
	47.11	US 62	16.337	College St.
	47.12	US 62	18.999	French St.
HARLAN	48.1	US 119	33.950	KY 179
HARRISON	49.1	US 27	5.816	KY 32
HENDERSON	51.1	US 41	10.871	KY 425
	51.2	US 41A	15.832	2th St.
	51.3	US 41A	15.736	1st St.
	51.4	US 41	17.524	Watson Lane
	51.5	US 41	16.921	Marywood
	51.6	US 60	8.712	KY425
HOPKINS	54.1	KY 70	19.946	KY 254
	54.2	US 41A	12.800	KY 336
	54.3	KY 281	0.051	Lantaff
JEFFERSON	56.1	KY 1065	8.515	Smyrne
	56.2	KY 1865	5.030	Bluegrass
	56.3	KY 1631	3.801	Hol. Towers
	56.4	KY 1631	3.985	I 65NB
	56.5	KY 146	0.983	Lyndon
	56.6	US 31E	6.529	Fairground
	56.7	US 60	10.408	Juneau
	56.8	US 60	10.751	Aiken
	56.9	KY 1932	3.519	I 264

TABLE 1. LIST OF INTERSECTIONS (Continued)

COUNTY	INTERSECTION NUMBER	ROUTE	MP	INTERSECTING ROUTE
JESSAMINE	57.1	US 27	5.803	US 27X
	57.2	US 27	6.767	Shun Pike
	57.3	US 27	9.552	KY 169
	57.4	US 27	12.602	Catnip Hill Rd.
	57.5	US 27	7.359	Edgewood Dr.
	57.6	US 27	8.601	Etter Dr.
	57.7	US 27	14.237	KY 1980
KENTON	59.1	KY 17	18.426	Dudley Rd.
	59.2	US 25	10.685	Kyles
	59.3	US 25	6.120	Hallam
	59.4	US 25	8.050	KY 1303
LARUE	62.1	KY 61	9.127	KY 84
	62.2	US 31E	8.454	KY 61-KY1618
LAUREL	63.1	KY 80	13.150	KY 192
	63.2	KY 192	18.474	KY 1006
	63.3	KY 192	19.100	KY 363
	63.4	KY 192	20.411	KY 229
	63.5	D B Pkwy	3.010	KY 472
	63.6	US 25	10.504	KY 192
LAWRENCE	64.1	US 23	18.410	KY 3
McCRACKEN	73.1	US 60	3.810	KY 996
	73.2	US 62	15.513	US 68
	73.3	US 60	11.218	KY 788 (Freidman)
	73.4	US 60	15.280	Brown
	73.5	US 45	7.200	Lakeview
McCREARY	74.1	US 27	4.608	KY 92
MADISON	76.1	KY 876	7.166	I-75
	76.2	KY 52	10.910	KY 876
MAGOFFIN	77.1	US 460	11.211	Mountain Pkwy.
MARSHALL	79.1	US 62	7.200	KY 95
	79.2	US 641	1.224	KY 80
	79.3	US 62	5.218	Purchase Pkwy.
	79.4	US 68	9.662	US 641

TABLE 1. LIST OF INTERSECTIONS (Continued)

COUNTY	INTERSECTION NUMBER	ROUTE	MP	INTERSECTING ROUTE
MASON	81.1	US 62	13.381	Clarks Run Rd.
	81.2	KY 9	9.280	US 62
MEADE	82.1	US 31W	0.559	US 60
	82.2	US 31W	2.325	KY 1638
MONTGOMERY	87.1	KY 11	9.246	KY 686
MORGAN	88.1	US 460	15.473	KY 191
	88.2	US 460	17.176	KY 2498
MUHLENBERG	89.1	US 62	8.780	KY 189
	89.1	KY 70	14.709	KY 189
	89.3	KY 181	12.460	KY 189
	89.4	KY 189	11.176	Green Dr.
PERRY	97.1	KY 15	13.513	Perry Co. Park Rd.
	97.2	KY 15	15.197	D B Pkwy
	97.3	D.B. Pkwy	59.088	Shopping Center
	97.4	KY 15	8.912	KY 451
PIKE	98.1	US 23	28.579	US 119
	98.2	US 23	29.775	KY 3227
	98.3	US 23	31.175	Weddington Br. Rd.
	98.4	US 119	2.672	KY 1426
PULASKI	100.1	US 27	12.360	KY 1642W
	100.2	US 27	12.862	KY 1642E
	100.3	US 27	12.630	Mall Ent.
	100.4	US 27	12.900	Bourbon Rd.
	100.5	US 27	13.905	Grand Central Pl.
ROWAN	103.1	US 60	10.036	KY 32
SCOTT	105.1	US 25	2.707	Showwalter
SIMPSON	107.1	KY 100	8.572	KY 1008
TAYLOR	109.1	KY 55	9.066	KY 3183
	109.2	KY 55	10.293	US 68
WARREN	114.1	US 31W	17.089	KY 1402
	114.2	KY 446	0.772	Corvette Dr.

TABLE 1. LIST OF INTERSECTIONS (Continued)

COUNTY	INTERSECTION NUMBER	ROUTE	MP	INTERSECTING ROUTE
WASHINGTON	115.1	US 150	8.556	KY 555
WAYNE	116.1	KY 90	9.601	KY 90X
WOODFORD	120.1	US 60	8.130	Merewood St.
	120.2	US 60	10.091	Paddock Dr.
	120.3	US 60	12.112	Huntertown Rd.
	120.4	US 60	9.385	US 60B

TABLE 2. CHARACTERISTICS OF APPROACH LOCATIONS

CATEGORY	VARIABLE	NUMBER OF APPROACHES
Speed Limit (mph)	35 or Less	131
	40 or 45	176
	50 or 55	211
Type of Phasing	Protected Only	190
	Protected/Permitted	168
	Permissive Only	160
Type of Phasing (SL >45 mph)	Protected Only	111
	Protected/Permitted	4
	Permissive Only	96
Left-Turn Phasing	Leading	345
	Lagging	13
Left-Turn Signal Configuration (MUTCD)	S	161
	M	7
	C	190
Number of Left-Turn Lanes	None	58
	1	452
	2	8
Number of Opposing Through Lanes	1	184
	2	330
	3	4
Regulatory Sign:		
P/P	Yes	41
	No	127
Permissive Only	Yes	15
	No	145

TABLE 3. SUMMARY OF LEFT-TURN ACCIDENTS

CATEGORY	ACCIDENTS PER YEAR	NUMBER OF APPROACHES	PROTECTED	PROTECTED/ PERMITTED	PERMISSIVE
Average Number	0.00-0.5	358	176	68	114
of Left-Turn Accidents	0.51-1.0	64	12	29	23
per Year	1.01-2.0	54	2	40	12
	2.01-3.0	23	0	16	7
	3.01-4.0	7	0	5	2
	4.01-5.0	8	0	6	2
	over 5.0	4	0	4	0

TABLE 4. COMPARISON OF TYPE OF ACCIDENT AND RELATED INJURY

	ALL ACCIDENTS	LEFT-TURN ACCIDENTS
Total	14,187	1,351
Injury	4,109	534
Percent Injury	29.0	39.5

TABLE 5. ACCIDENT ANALYSIS BASED ON TYPE OF PHASING AND SPEED LIMIT

SPEED LIMIT (mph)	PHASING	NUMBER OF APPROACHES*	AVG. LT ACC. PER APP.	AVG. PEAK HR. LT. VOLUME	AVG. PEAK HR. OPP. VOLUME	AVG. LT. ACC. PER 100 LT. VEH.	AVG. LT. ACC. PER 1,000 LT+OPP VEH	AVG. LT. ACC. PER 100,000 LT X OPP VEH
All	Protected	127	0.20	113	641	0.18	0.27	0.28
	P/P	142	1.32	152	855	0.87	1.31	1.02
	Permissive	139	0.50	68	424	0.74	1.02	1.73
35 or less	Protected	3	0.33	65	406	0.51	0.70	1.25
	P/P	75	0.74	126	677	0.59	0.92	0.87
	Permissive	30	0.73	92	342	0.79	1.68	2.32
40 - 45	Protected	42	0.29	139	835	0.21	0.30	0.25
	P/P	63	2.04	190	1071	1.07	1.62	1.00
	Permissive	21	0.38	51	327	0.75	1.01	2.28
50 - 55	Protected	82	0.15	102	550	0.15	0.23	0.27
	P/P	4	0.75	84	781	0.89	0.87	1.14
	Permissive	88	0.45	64	475	0.70	0.83	1.48

* Only included approaches with volume counts.

TABLE 6. ACCIDENT ANALYSIS BASED ON TYPE OF PHASING, SPEED LIMIT AND NUMBER OF OPPOSING LANES

Speed Limit (mph)	NUMBER OF OPPOSING LANES	PHASING	NUMBER OF APPROACHES*	AVG. LT ACC. PER APP.	AVG. PEAK HR. LT. VOLUME	AVG. PEAK HR. OPP. VOLUME	AVG. LT. ACC. PER 100 LT. VEH.	AVG. LT. ACC. PER 1,000 LT+OPP VEH	AVG. LT. ACC. PER 100,000 LT X OPP VEH
All	1	Protected	23	0.11	92	217	0.12	0.36	0.55
		P/P	52	0.53	144	463	0.37	0.87	0.79
		Permissive	77	0.39	72	248	0.54	1.22	2.18
	2	Protected	102	0.23	117	706	0.20	0.28	0.28
		P/P	88	1.79	153	1077	1.17	1.46	1.09
		Permissive	62	0.62	64	642	0.97	0.88	1.51
35 or Less	1	Protected	0	NA	NA	NA	NA	NA	NA
		P/P	45	0.51	139	457	0.37	0.86	0.80
		Permissive	21	0.66	102	267	0.65	1.79	2.42
	2	Protected	3	0.33	65	406	0.51	0.70	1.25
		P/P	30	1.1	107	1006	1.03	0.99	1.02
		Permissive	9	0.89	69	517	1.29	1.52	2.49
40 or 45	1	Protected	5	0.25	86	239	0.29	0.77	1.22
		P/P	7	0.71	180	501	0.39	1.04	0.79
		Permissive	17	0.28	50	299	0.56	0.80	1.87
	2	Protected	37	0.3	146	916	0.21	0.28	0.22
		P/P	54	2.25	184	1138	1.22	1.70	1.07
		Permissive	4	0.81	55	448	1.47	1.61	3.29
50 or 55	1	Protected	18	0.07	94	211	0.07	0.23	0.35
		P/P	0	NA	NA	NA	NA	NA	NA
		Permissive	39	0.30	64	216	0.47	1.07	2.17
	2	Protected	62	0.18	103	595	0.17	0.26	0.29
		P/P	4	0.75	84	781	0.89	0.87	1.14
		Permissive	49	0.56	64	680	0.88	0.75	1.29

* Only included approaches with volume counts.

TABLE 7. CHARACTERISTICS OF INTERSECTIONS RELATED TO ACCIDENT DATA

CATEGORY	PHASING	VARIABLE	NUMBER OF APPROACHES	AVG. NUMBER OF LT ACC. PER APPROACH
Left-Turn Phasing	Prot. Only	Leading	189	0.20
		Lagging	1	0.50
	P/P	Leading	156	1.27
		Lagging	11	2.07
Left-Turn Signal Configuration	P/P	S	161	1.36
		M	7	0.46
Number of Left-Turn Lanes	Prot. Only	1	189	0.19
		2	7	0.39
	P/P	None	10	2.12
		1	157	1.24
		2	1	6.50
	Perm. Only	None	48	0.68
		1	112	0.54
Regulatory Sign	P/P	Yes	41	1.18
		No	127	1.37
	Perm. Only	Yes	15	0.60
		No	145	0.58

TABLE 8. CHARACTERISTICS OF P/P LOCATIONS VERSUS ACCIDENT HISTORY

		LEFT TURN ACCIDENTS PER YEAR		
CATEGORY	VARIABLE	1.0 OR LESS	1.01 -2.0	GREATER THAN 2.0
Speed Limit (mph)	35 or less	68	14	10
	40 - 45	26	25	21
	50 - 55	3	1	0
Number of Left-Turn Lanes	0	2	3	5
	1	95	37	25
	2	0	0	1
Number of Opposing Lanes	1	51	8	4
	2	45	31	27
	3	1	1	0
Left-Turn Volume	50 or Less	21	7	1
	51 - 100	18	6	2
	101 - 200	36	6	8
	201 -300	7	10	8
	> 300	2	2	8
Opposing Volume	250 or Less	9	0	1
	251 - 500	24	3	2
	501 - 750	18	7	6
	> 750	33	21	18
Opposing Volume (1 Opposing Lane)	250 or Less	15	4	2
	251 - 500	22	2	0
	> 500	14	2	2
Opposing Volume (2 Opposing Lanes)	500 or Less	9	6	5
	501 - 1,000	20	12	7
	> 1,000	16	13	15
LT X OPP Volume (1 Opposing Lane)	25,000 or Less	15	0	0
	25,001 - 50,000	13	1	0
	50,001 - 75,000	6	1	0
	75,001 - 100,000	4	0	0
	100,001 - 125,000	2	1	1
	125,001 - 150,000	2	1	0
	> 150,000	3	0	2
LT X OPP Volume (2 Opposing Lanes)	50,000 or Less	11	8	2
	50,001 - 100,000	14	3	3
	100,001-200,000	7	8	1
	200,001-300,000	5	5	8
	300,001-400,000	1	1	3
	> 400,000	0	1	7

TABLE 9. SUMMARY OF CONFLICT DATA (CONTINUED)

INTERSECTION	NUMBER	APPROACH	LT ACC/ YEAR	PEAK HOUR CONFLICTS	PERCENT TURNING ON PERMISSIVE	LT VOLUME	OPPOSING VOLUME	CONFLICTS PER 100 LT	CONFLICTS PER 1,000 LT+OPP	CONFLICTS PER 100,000 LT*OPP
Man O War - Alumni	34.73	NB	7.0	9	45	278	888	3.2	7.7	3.65
		SB	1.7	2	58	43	722	4.7	2.6	6.44
		EB	2.7	2	21	310	125	0.6	4.6	5.16
		WB	0.7	0	42	31	302	0.0	0.0	0.00
Alumni - New Circle	34.77	Inner	2.7	8	52	435	884	1.8	6.1	2.08
	34.78	Outer	13.0	7	7	532	1138	1.3	4.2	1.16
Clays Mill - Pasadena	34.66	NB	2.7	7	42	187	623	3.7	8.6	6.01
		SB	0.0	2	37	52	506	3.8	3.6	7.60
		EB	0.0	1	26	80	460	1.3	1.9	2.72
		WB	1.7	4	23	235	598	1.7	4.8	2.85
Clays Mill - Reynolds	34.67	SB	1.0	3	24	319	878	0.9	2.5	1.07
Clays Mill - Wellington	34.68	NB	0.3	7	42	184	1084	3.8	5.5	3.51
Man O War - Boston	34.69	EB	1.7	3	42	234	791	1.3	2.9	1.62
		WB	1.3	2	38	289	904	0.7	1.7	0.77
Man O War - Todds	34.70	NB	0.7	5	21	261	204	1.9	10.8	9.39
		SB	0.7	1	27	175	130	0.6	3.3	4.40
		EB	1.7	1	42	38	844	2.6	1.1	3.12
		WB	0.3	1	57	49	854	2.0	1.1	2.39
Man O War - Pimlico	34.71	NB	0.7	1	76	192	1112	0.5	0.8	0.47
		SB	0.7	1	81	27	909	3.7	1.1	4.07
Man O War - Clays Mill	34.72	NB	0.0	1	26	66	299	1.5	2.7	5.07
		SB	0.3	1	25	116	185	0.9	3.3	4.66
		EB	2.0	2	30	125	716	1.6	2.4	2.23
		WB	2.3	3	59	102	636	2.9	4.1	4.62
Man O War - Armstrong Mill	34.74	NB	0.0	0	29	76	208	0.0	0.0	0.00
		SB	0.0	1	21	86	219	1.2	3.3	5.31
		EB	0.3	0	55	22	571	0.0	0.0	0.00
		WB	1.7	2	53	108	780	1.9	2.3	2.37

TABLE 9. SUMMARY OF CONFLICT DATA (CONTINUED)

INTERSECTION	NUMBER	APPROACH	LT ACC/ YEAR	PEAK HOUR CONFLICTS	PERCENT TURNING ON PERMISSIVE	LT VOLUME	OPPOSING VOLUME	CONFLICTS PER 100 LT	CONFLICTS PER 1,000 LT+OPP	CONFLICTS PER 100,000 LT*OPP
Man O War - Palumbo	34.75	EB	1.3	1	42	64	1404	1.6	0.7	1.11
		WB	1.3	4	33	230	1238	1.7	2.7	1.40
Alumni - Yellowstone	34.76	NB	0.7	3	16	202	295	1.5	6.0	5.03
		SB	0.7	1	19	100	151	1.0	4.0	6.62
		EB	3.0	4	27	341	717	1.2	3.8	1.64
		WB	1.7	1	80	10	952	10.0	1.0	10.50
Richmond - Man O War	34.16	EB	5.0	12	14	344	767	3.5	10.8	4.55
		WB	6.5	6	7	448	1375	1.3	3.3	0.97
US 25 - Squires	34.11	SB	0.0	6	63	43	1114	14.0	5.2	12.53
		NB	1.0	1	80	54	920	1.9	1.0	2.01
KY 1974- Man O War	34.53	SB	0.5	2	54	98	476	2.0	3.5	4.29
		NB	1.3	10	33	142	1123	7.0	7.9	6.27
KY 1974- Wilson Downing	34.54	SB	1.5	0	42	72	609	0.0	0.0	0.00
		NB	2.8	2	52	113	663	1.8	2.6	2.67
US 25 - Rose	34.25	NB	6.5	5	53	264	407	1.9	7.5	4.65
KY 1974- New Circle	34.57	NB	4.8	8	14	338	1508	2.4	4.3	1.57
		SB	2.8	9	40	198	1397	4.5	5.6	3.25
Southland - US 27	34.32	EB	0.0	3	16	287	218	1.0	5.9	4.79
		WB	0.0	1	25	56	548	1.8	1.7	3.26
US 68 - New Circle		NB	3.0	5	47	278	1168	1.8	3.5	1.54
	34.1	SB	2.8	9	17	406	1050	2.2	6.2	2.11
US 68 - Ft. Harrods	34.7	NB	0.5	3	*	41	828	7.3	3.5	8.84
		SB	1.0	3	*	52	827	5.8	3.4	6.98
US 25 - Locust Hill	34.15	EB	3.2	3	34	223	1037	1.3	2.4	1.30
		WB	5.0	6	20	235	741	2.6	6.1	3.45

TABLE 9. SUMMARY OF CONFLICT DATA (CONTINUED)

INTERSECTION	NUMBER	APPROACH	LT ACC/ YEAR	PEAK HOUR CONFLICTS	PERCENT TURNING ON PERMISSIVE	LT VOLUME	OPPOSING VOLUME	CONFLICTS PER 100 LT	CONFLICTS PER 1,000 LT+OPP	CONFLICTS PER 100,000 LT*OPP
US 25 - Patchen	34.18	EB	4.2	5	11	212	1494	2.4	2.9	1.58
		WB	0.5	1	27	123	1376	0.8	0.7	0.59
US 60 - Paddock	120.2	WB	0.2	2	*	28	1260	7.1	1.6	5.67
KY 1974 - Gainesway Dr.	34.56	SB	1.5	6	100	233	1204	2.6	4.2	2.14
US 27- Leader	34.33	NB	0.7	0	82	11	1287	0	0	0

* Permissive Only Phasing

Figure 1. Left-Turn Accidents per Year vs. Left-Turn Volume (One Opposing Lane)

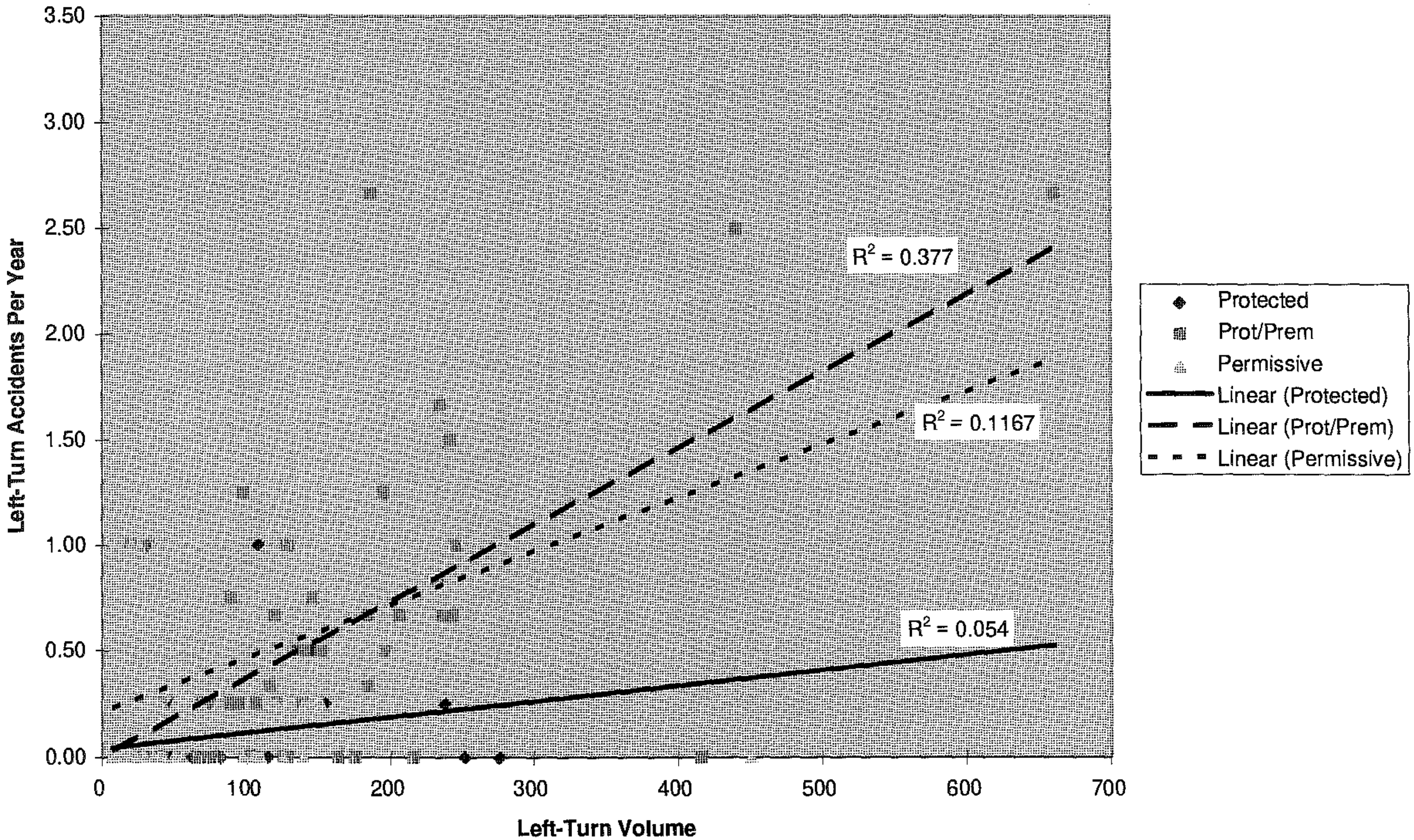


Figure 2. Left-Turn Accidents per Year vs. Left-Turn Volume (Two Opposing Lanes)

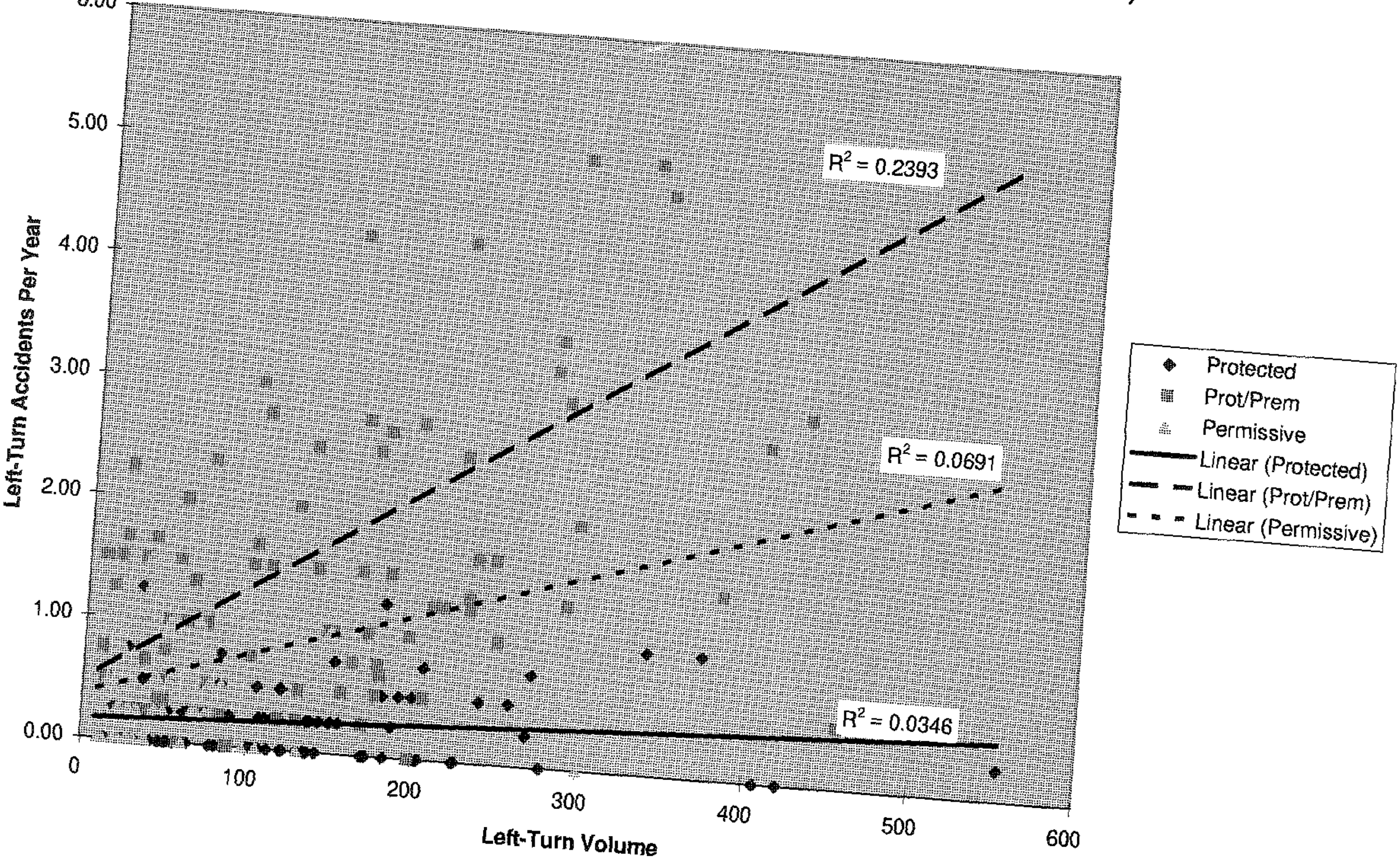


Figure 3. Left-Turn Accidents per Year vs. Opposing Volume (One Opposing Lane)

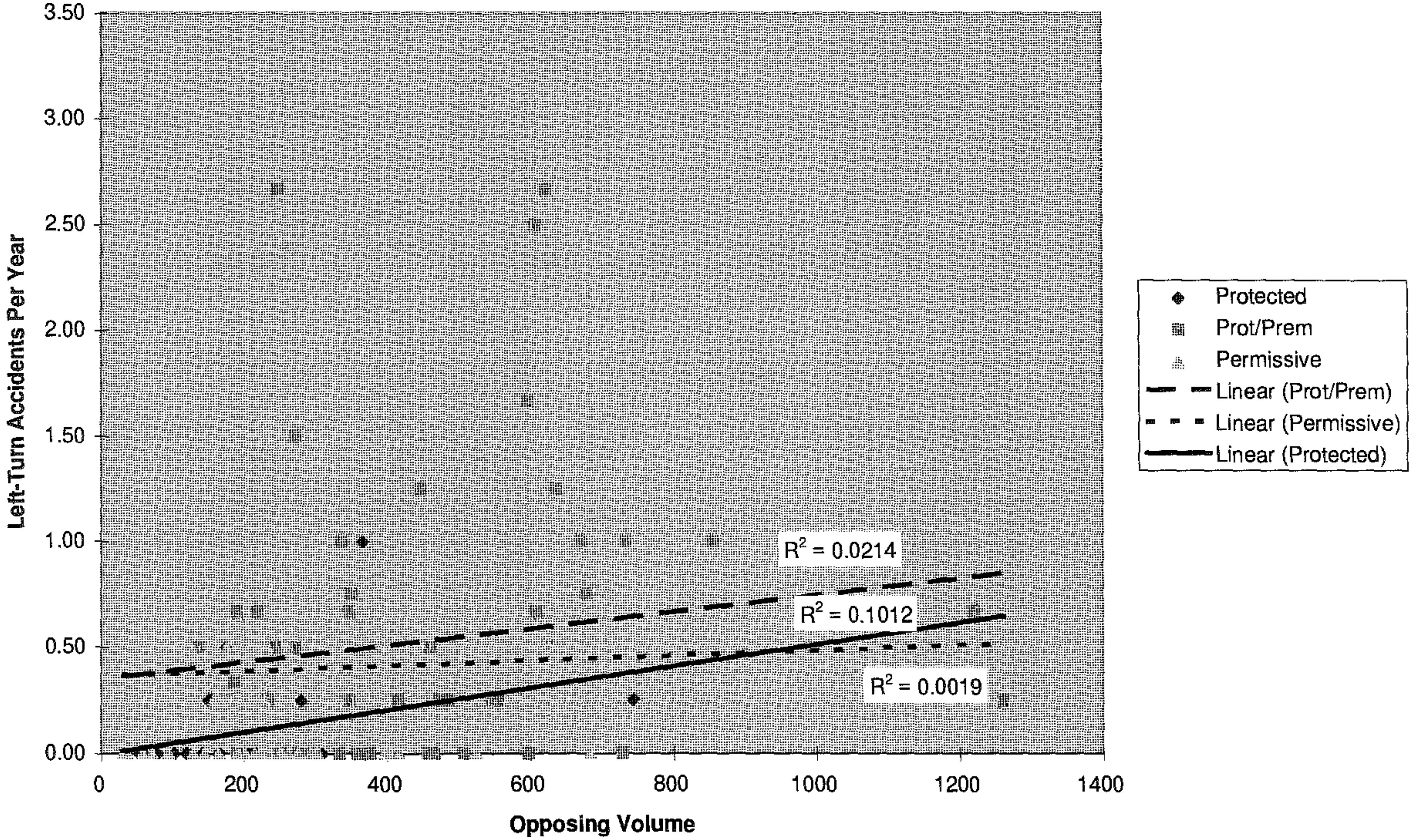


Figure 4. Left-Turn Accidents per Year vs. Opposing Volume (Two Opposing Lanes)

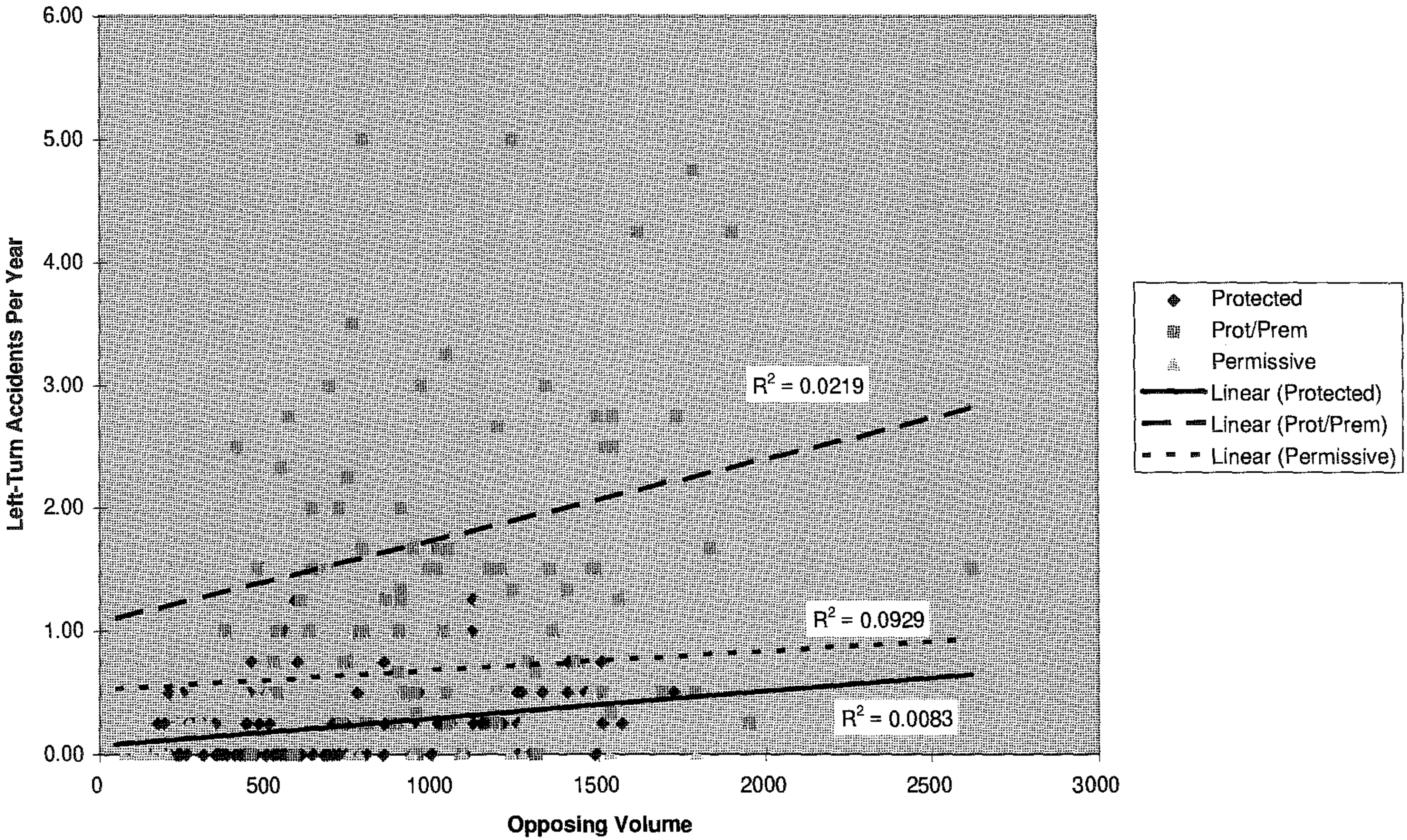


Figure 5. Left-Turn Accidents per Year vs. Product of Left-Turn and Opposing Volumes (One Opposing Lane)

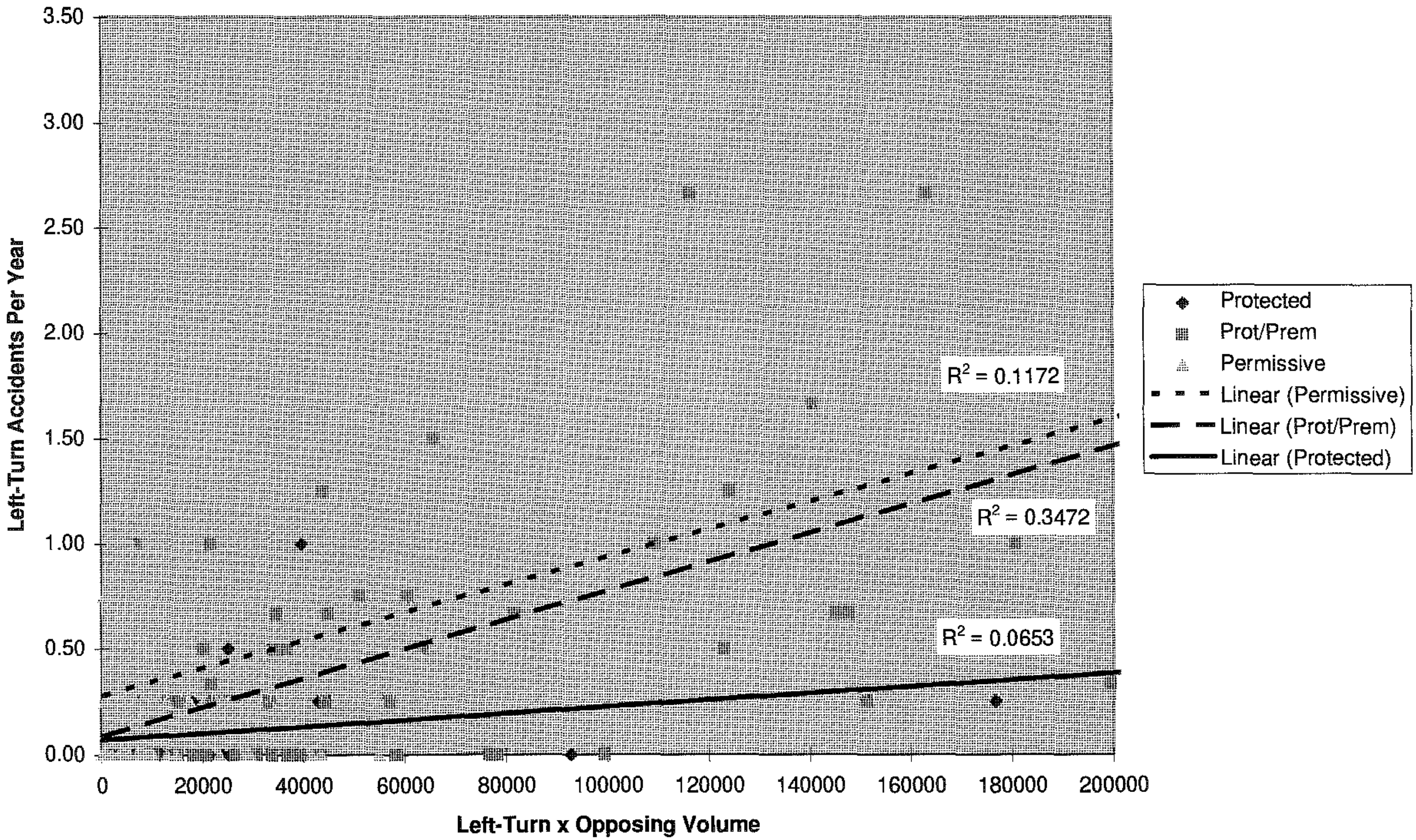


Figure 6. Left-Turn Accidents per Year vs. Product of Left-Turn and Opposing Volumes (Two Opposing Lanes)

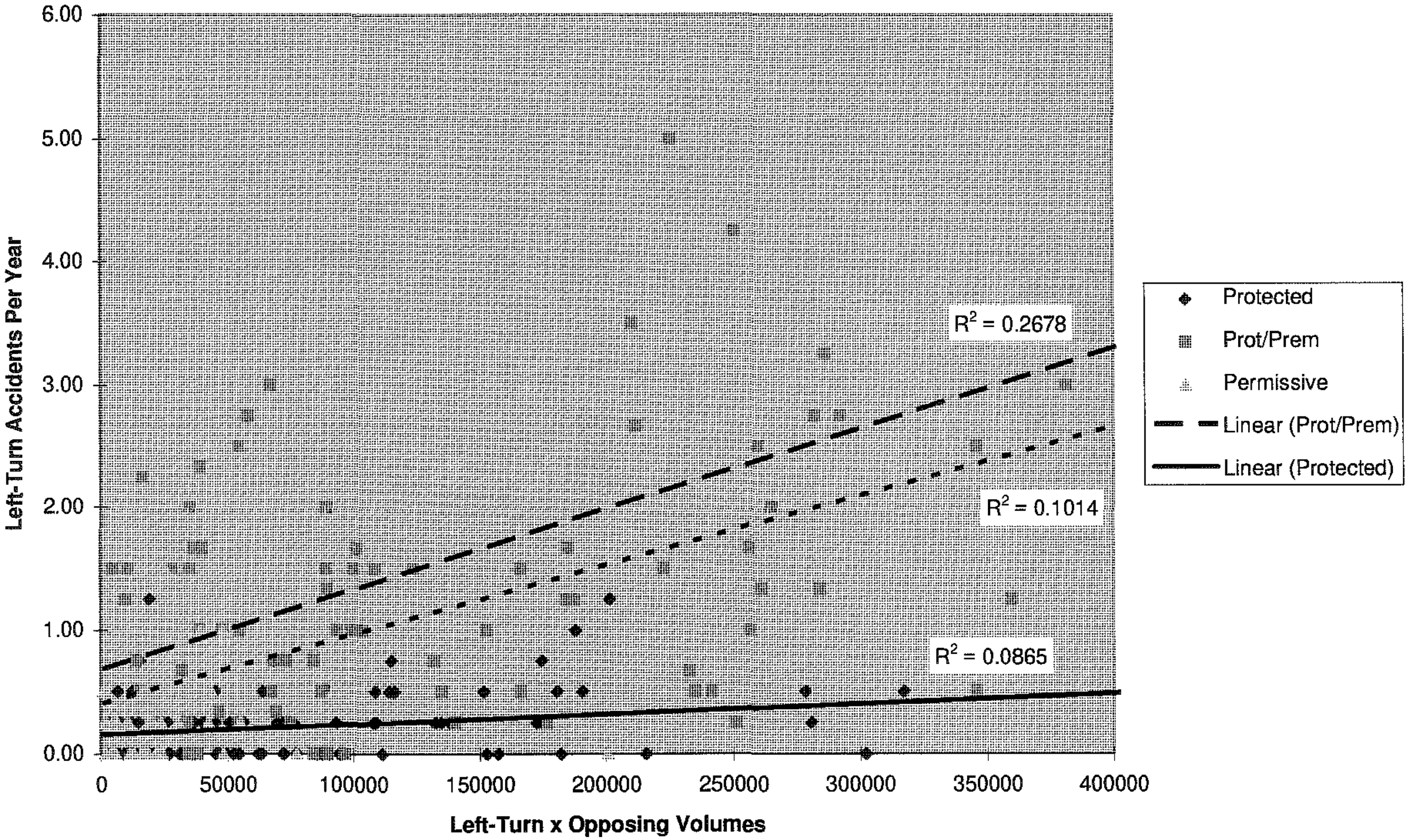


Figure 7. Relationship Between Left-Turn Accidents per Year and Peak Hour Left-Turn Conflicts.

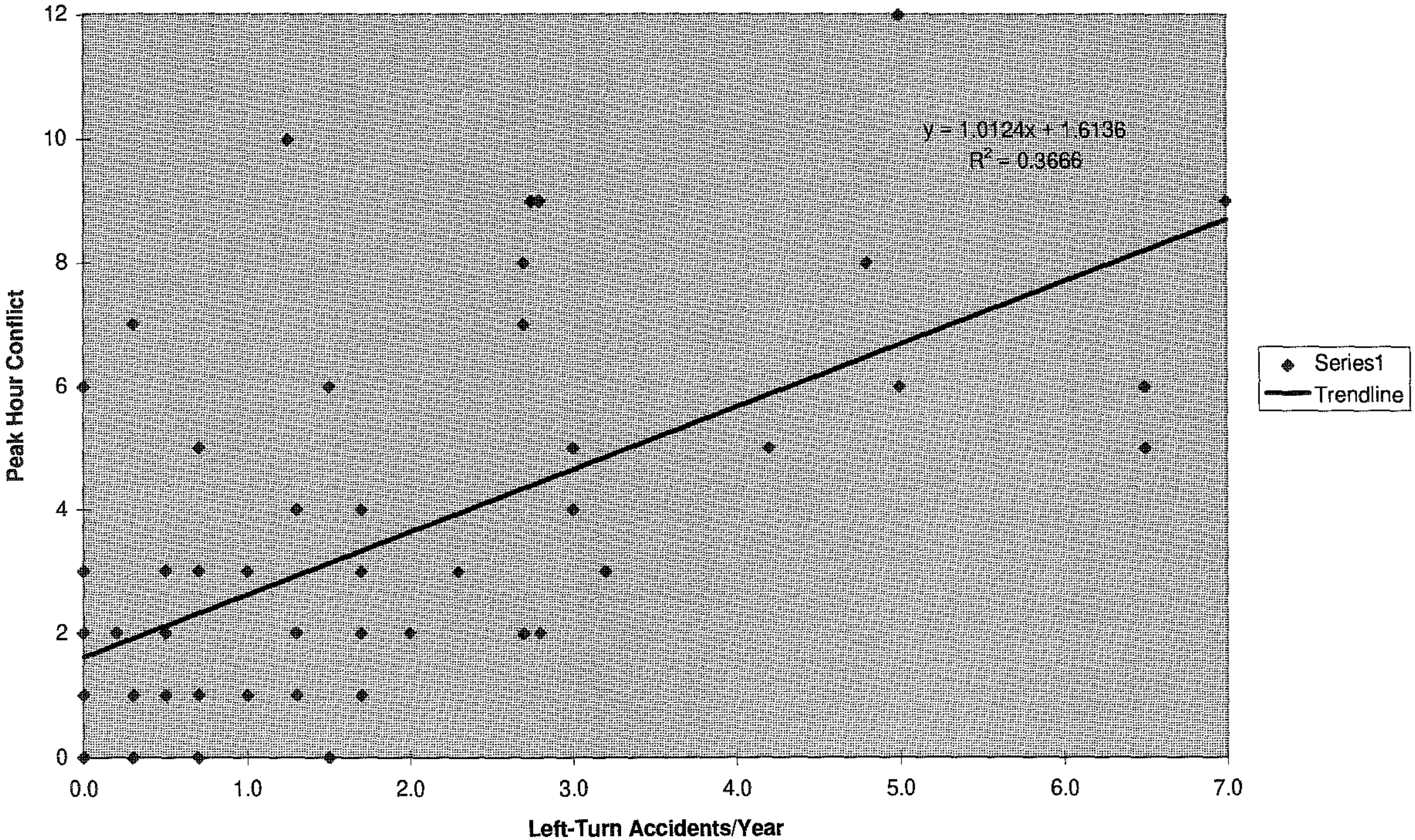


Figure 8. Relationship Between Peak Hour Left-Turn Conflicts and Left-Turn Volume

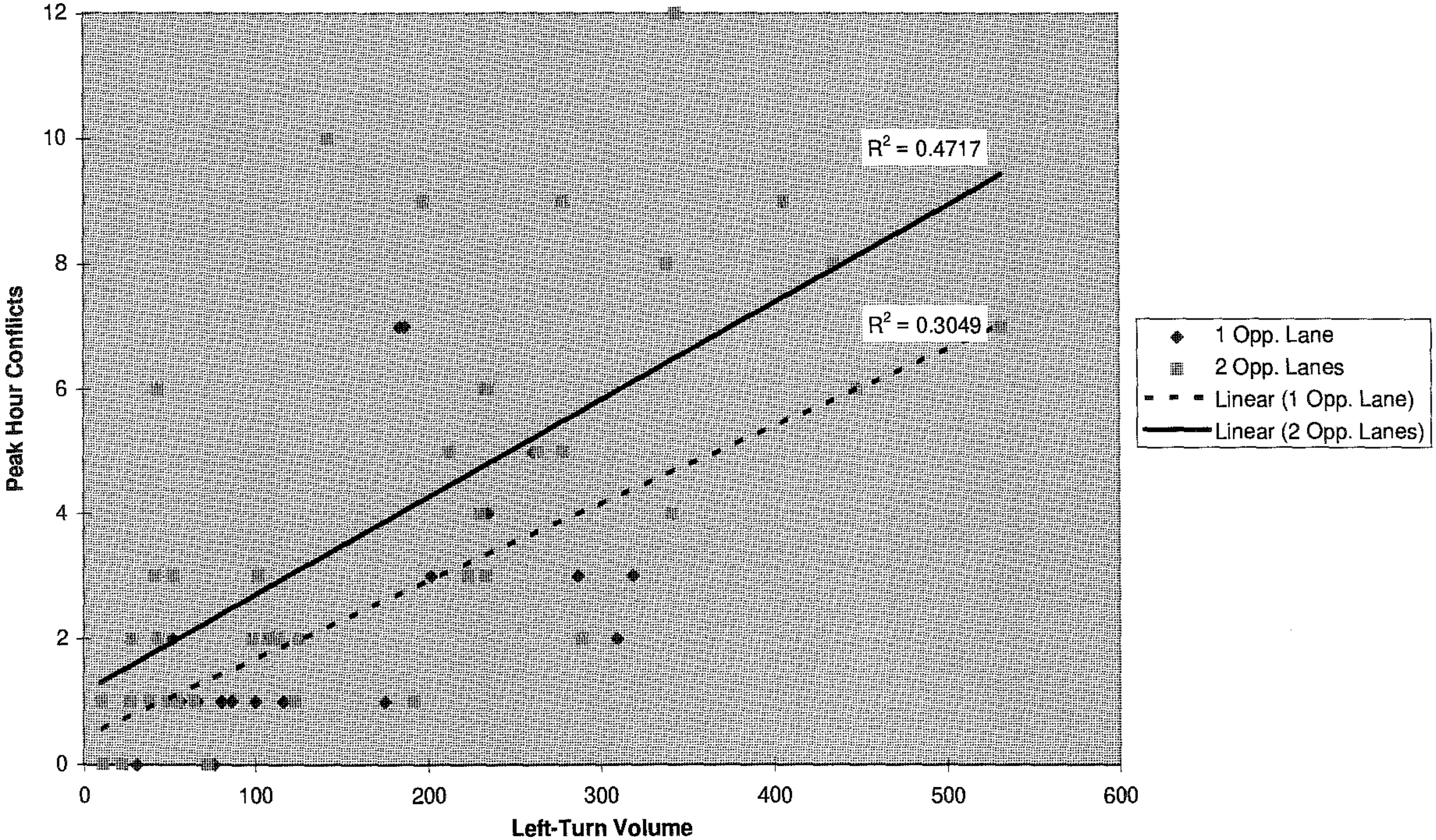


Figure 9. Relationship Between Peak Hour Left-Turn Conflicts and Opposing Volume

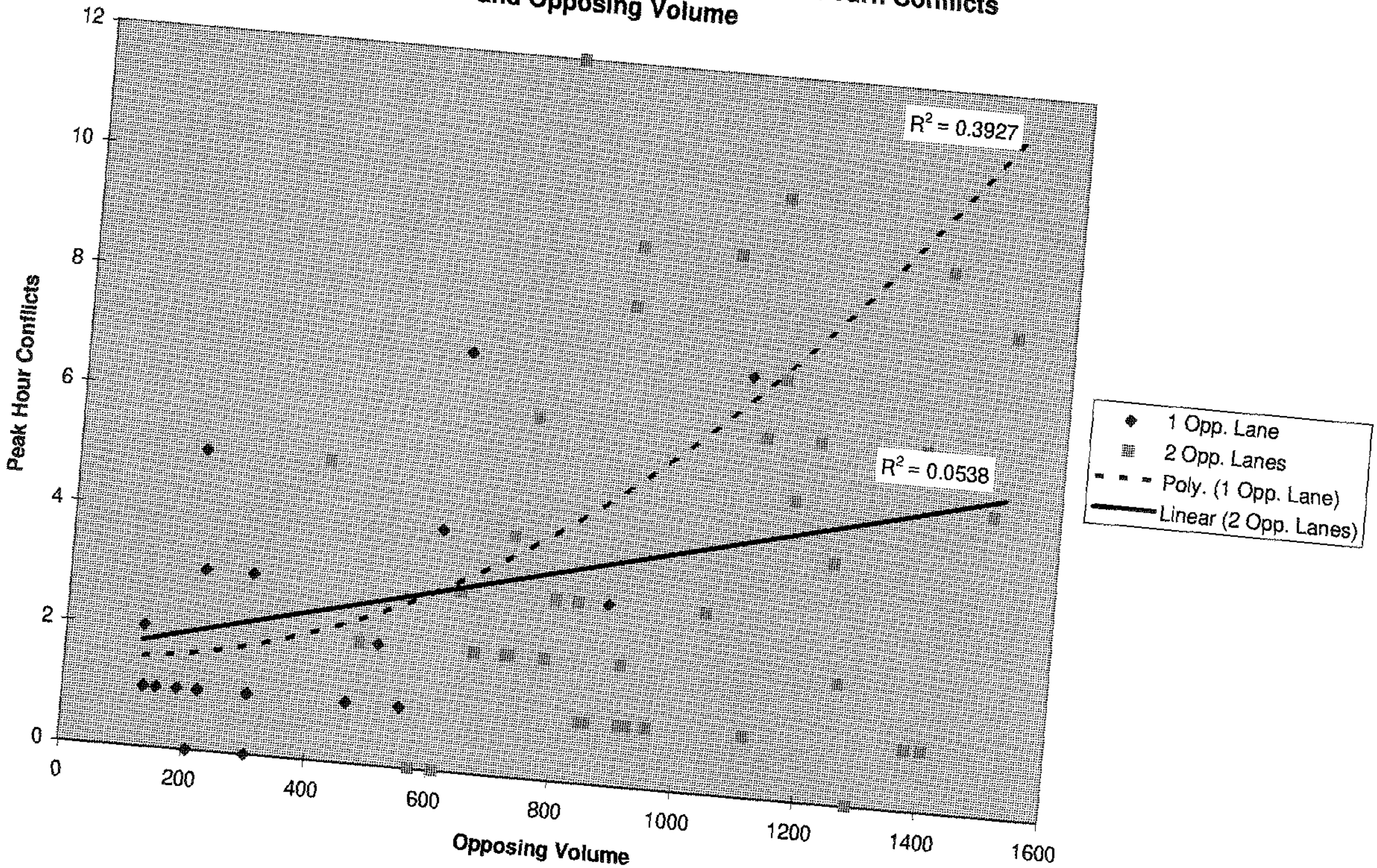
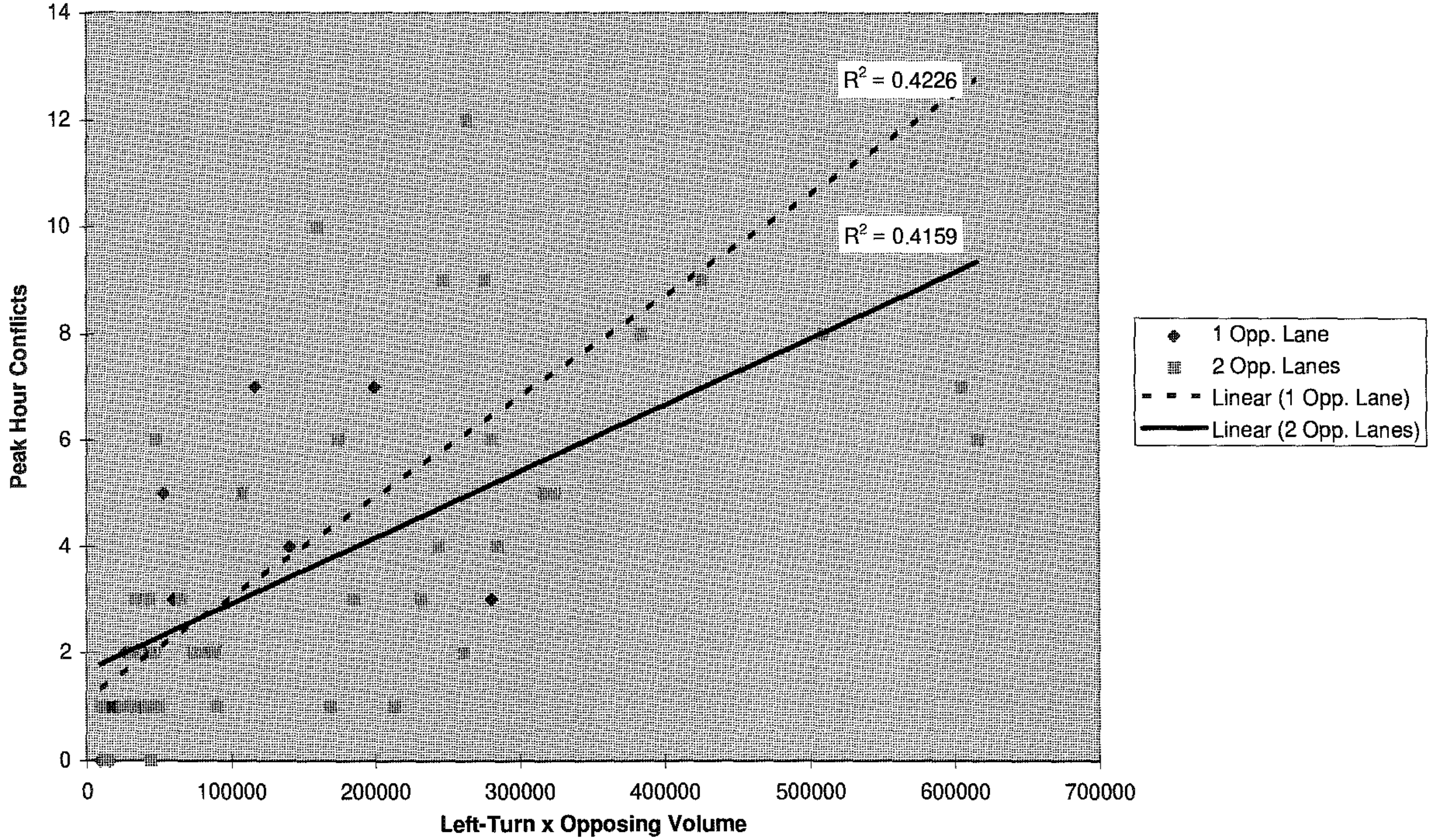


Figure 10. Relationship Between Peak Hour Left-Turn Conflicts and the Product of Left-Turn and Opposing Volumes



APPENDIX A

REVIEW OF LITERATURE

"A Study of Clearance Intervals, Flashing Operation, and Left-Turn Phasing at Traffic Signals," Federal Highway Administration, Report No. FHWA-RD-78-46, May 1980.

One section of this report considered signal phasing that allows vehicles to make left turns during both a protected (green arrow) interval and an unprotected (green ball) interval. The study included a literature review, a review of state laws, questionnaires to public officials and to drivers, analytical models of traffic flow, and field studies to arrive at the recommendations. Following are the primary conclusions resulting from this study:

1. The use of protected/permitted left-turn phasing will:
   a. reduce delays to all vehicles entering the intersection.
   b. increase left-turn accidents.
2. Use of the yellow arrow following a leading green arrow results in improved operating conditions.
3. The present level of public understanding of the meaning of the green ball when used following the green arrow is unacceptably low.
4. Correct public understanding of the signal display is more important than the technical aspects of the protected/permitted technique.
5. Uniformity of the display for protected/permitted is needed.

"Accident Analysis of Left-Turn Phasing", Maryland, 1984.

This study compared accident data at several intersections with protected- only and protected/permitted phasing. The effect of converting to protected/permitted left-turn phasing was found to affect the type of accidents occurring. At intersections previously without left-turn signals, left-turn, rear end, and total accidents generally decreased with left-turn accidents showing a 50 percent drop. At intersections converted from protected-only to protected/permitted left-turn phasing, left-turn accidents generally increased (from four per year/intersection to six per year/intersection) while rear-end accidents dropped.

Agent, K. R.; "Development of Warrants for Left-Turn Phasing," Kentucky Department of Transportation, Research Report 456, August 1976.

Warrants for the installation of left-turn phasing were developed. A review of literature was conducted along with a survey of the polices of other states. Various types of data collection were conducted. The following warrants were recommended when considering addition of separate left-turn phasing. The warrants apply to intersection approaches having a separate left-turn lane.

1. Accident Experience - Install left-turn phasing if the critical number of left-turn accidents have occurred. For one approach, four left-turn accidents in one year or six in two years are critical. For both approaches, six left-turn accidents in one year or ten in two years are critical.

2. Delay - Install left-turn phasing if a left-turn delay of 2.0 vehicle-hours or more occurs in a peak hour on a critical approach. Also, there must be a minimum left-turn volume of 50 during the peak hour, and the average delay per left-turning vehicle must be at least 35 seconds.

3. Volumes - Consider left-turn phasing when the product of left-turning and opposing volumes during peak hours exceeds 100,000 on a four-lane street or 50,000 on a two-lane street. Also, the left-turning volume must be at least 50 during the peak-hour period. Volumes meeting these levels indicate that further study of the intersection is required.

4. Traffic Conflicts - Consider left-turn phasing when a consistent average of 14 or more total left-turn conflicts or 10 or more basic left-turn conflicts occur in a peak hour.

Agent, K. R.; "An Evaluation of Permissive Left-Turn Phasing," Kentucky Department of Transportation, Research Report 519, April 1979.

In this study, exclusive left-turn phasing was replaced with permissive left-turn phasing (protected/permitted and permitted/protected) at four trial intersections. Delay and accident studies were conducted before and after the trial installations. Also, a questionnaire was issued to determine public opinion concerning the signals.

The use of permissive-turn phasing resulted in a 50-percent reduction in left-turn delay and a 24-percent reduction in total delay compared to exclusive phasing. The permissive left-turn phasing resulted in an increase in left-turn accidents. However, other accident types, such as rear-end accidents, did not increase. The number of left-turn accidents decreased as drivers became more familiar with the signals. Questionnaire responses showed that over 90 percent of drivers were in favor of this type of signal.

Agent, K. R.; "Guidelines for the Use of Protected/permitted Left-Turn Phasing," Kentucky Transportation Research Program, Research Report UKTRP-85-19, August 1985.

The purpose of this study was to develop guidelines that may be used to aid the traffic engineer in deciding whether protected/permitted phasing is appropriate to use at a given location. Protected/permitted is the perferable method of left-turn phasing because of saving in time compared to protected-only phasing. However, it creates an increased accident potential and should not be used when any of the following conditions exist:

1. speed limit 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),
7. a potential left-turn problem exists as documented by a traffic conflicts study, or
8. sight distance below that given below for various speeds.

When protected/permitted 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" should be used when the protected portion of the phase is leading,
3. lense arrangement "m" should be used when the protected portion of the phase is lagging, and
4. no regulatory sign is necessary.

"An Evaluation of Exclusive and Exclusive-Permissive Left Turn Signal Phasing," Maryland Department of Transportation, April 1981.

The study found that an exclusive-permissive (EP) left-turn phase could reduce left-turn delays by approximately 30 percent and as much as 50 percent. Left-turn delays versus left-turn volumes were found to have a linear relationship up to capacity conditions. Traffic conflicts can be expected to be higher at an EP signal than at an exclusive (E) signal. Accident experience at an E signal may not increase significantly when changed to EP. Based on the available data, the critical number of accidents at an EP signal has been determined to be 10 per year. A set of traffic parameters was noted to consider when designing left-turn phasing. These include speed of opposing traffic, grades, acceptable gaps, estimated delays, and geometries. It was noted that EP phasing might result in operational difficulties when.

1. The median between the left edge of opposing left-turn lanes exceeds 20 feet.
2. There is a median between left-turn lanes and the lane opposite the permissive phase has more than approximately 20 percent trucks large enough to obstruct the view of oncoming traffic.
3. There is not sufficient sight distance downstream for a motorist making a left turn to see an adequate gap in the opposing traffic stream.
4. The safe stopping sight distance for the opposing through traffic meets or exceeds the distance it would travel during an acceptable gap.
5. The speed of opposing through traffic is high or is subject to considerable fluctuations.
6. Double left turns are operating.

Asante, S. A.; and Williams; "Selection Criteria for Left-Turn Phasing and Indication Sequence, " Transportation Research Board Record 1421, 1993.

The objective of this study was to develop guidelines for appropriate left- turn phasing. The phasing patterns considered included protected only (PTO), protected/permitted (P/P), permissive only (PMO), and Dallas phasing. Data were collected from over 100 sites in nine counties across Texas. Site selection parameters included geometry, approach speeds, and signal phasing types and sequence. These included combinations of six opposing speed limits (30 to 55 mph in 5-mph increments); three opposing lanes (one, two, three); two left-turn lanes (one and two); and six phase patterns (leading protected only, lagging protected only, leading and lagging protected permissive, permissive only, and Dallas phasing).

The accident studies were concentrated at 42 intersections. A three-year history was obtained at each site. Only accidents involving left turns were extracted for analysis. Accident totals, rather than rates, were used.

P/P approaches have significantly higher left-turn accidents totals than PTO approaches. Low left-turn accident totals for PMO approaches occurred because they are generally low-volume intersections with no accident problem. A guideline using the accident analysis was established for what constitutes an excessive number of left-turn accidents for P/P phasing treatment. The 85th-percentile accident numbers were selected as a criterion. The 85th-percentile, three-year left-turn accident total was eight for P/P approaches and six for PTO approaches.

Following is a list of guidelines developed by this study. They were developed for intersections with little or no pedestrian traffic and with exclusive lanes for protected left turns.

Level 1. PMO Versus Some Protection

PMO should be replaced by some protection when one of the following exist.

1. The sight distance is restricted.
2. More than eight left turn related accidents have occurred on an approach within the last three years.
3. More than 450 left turn conflicts per million left turning vehicles are observed at an approach.
4. The plotted point representating the peak-period volume and the opposing traffic speed limit falls above a curve given in the report for the existing number of opposing lanes.

Level 2. P/P Versus PTO

P/P should be used unless PTO is absolutely necessary. PTO is recommended under any of the following conditions.

1. Restricted sight distance.
2. Four or more opposing lanes that must be crossed by the left-turning traffic.
3. Any two of the following conditions:
   a. Peak-hour left turn volume greater than 320 vph.
   b. Peak-hour opposing volume greater than 1,100 vph.
   c. Opposing speed limit greater than or equal to 45mph.
   d. Two or more left-turn lanes.
4. When one of the following conditions or combination of conditions exist:
   a. Three opposing lanes and opposing speed greater than 45 mph.
   b. Left turn volume greater than 320 vph and over 2.5 percent heavy vehicles in left-turning traffic.
   c. Opposing volume greater than 1,100 vph and over 2.5 percent of heavy vehicles in the left turning traffic.
   d. Seven or more left-turn related accidents within a 3-year period for P/P approach.
   e. More than 260 left-turn related conflicts per million left turning vehicles for a P/Papproach

Bonneson, J. A. and McCoy, P. T.; "Driver Understanding of Protected and Permitted Left-Turn Signal Displays," Transportation Reasearch Board Record 1464, 1994.

Driver comprehension of protected and permitted left-turn (PPLT) signal designs was evaluated by conducting a survey of 1,610 drivers. The survey questions were focused on four display indications in six different PPLT designs. The results indicate that drivers are better able to understand PPLT designs with any of the following characteristics: a modified protected indication, the PPLT head centered over the opposing left-turn lane, and no auxiliary signs. Both shared and exclusive designs were used but, in both instances, three heads were used on the approach. The exclusive vertical design was understood by the highest proportion of drivers. The analysis indicated that designs with a sign decrease driver understanding by about 6.5 percent.

Bonneson, J.A. and McCoy, P.T.; "Operational Analysis of Exclusive Left-Turn Lanes with Protected/permitted Phasing," Transportation Research Board Record 1114, 1987.

This paper reviewed some of the inconsistencies with the 1985 release of the Highway Capacity Manual. The manual contains procedures for evaluating the capacity and level of service of a signalized intersection. It was noted that revisions on the manual were needed with regard to the analysis of left-turn lane groups with protected/permitted phasing.

Clark, E.; "Guidelines for Left-Turn Phasing," ITE News of the South, Fall 1995.

This paper summarized a study conducted for the South Carolina DOT to develop guidelines for the use of left-turn phasing at signalized intersections. The basis of the guidelines was a review of literature and survey of highway agencies.

Permitted left turns should be replaced by a phase that provides some left-turn protection when any of the following conditions exist.

1. three or more left-turn accidents per year on an approach and the combination of peak left-turn volume and opposing volume exceeds a certain threshold which varies by speed limit,
2. sight distance is restricted (based on speed limit),
3. six or more left-turn accidents in a two-year period on an approach without left-turn phasing,

4. product of left-turn and opposing through volumes divided by the number of opposing lanes exceeds 50,000, and
5. delay to left-turning vehicles over two signal cycles during peak hour.

After the decision is made to place left-turn phasing, protected-only phasing is recommended when any of the following conditions exist.

1. sight distance is restricted (based on speed limit),
2. three or more opposing lanes and speed of 45 mph or above,
3. left-turning volume exceeds 320 vph with over 2.5 percent heavy vehicles,
4. opposing volume exceeds 1,100 vph with over 2.5 percent heavy vehicles,
5. four or more left-turn accidents in one year or six or more in two years on an approach with P/P phasing, or
6. two of the following conditions,
   a. peak 15-minute left-turn flow rate over 320 vph,
   b. peak 12-minute opposing flow rate over 1,100 vph,
   c. opposing speed limit 45 mph or greater, or
   d. double or more left-turn lanes.

Clark, J.E. and Daniel, J. T.; "Quantitations of the Impacts of Providing Protected Left Turns at Signalized Intersections," Clemson University, May 1994.

This report documented the development of guidelines and recommendations for the selection of left-turn phasing and loop detector locations for left-turn phasing. Recommendations regarding the type of left-turn phasing are based on a two-level decision process. The first level of the decision process provides guidelines relating to whether no left-turn phasing is adequate. The second level provides recommendations to assist in determining if the less restrictive protected/permitted phasing is adequate.

Level 1. No Left-Turn Phasing or Some Protection Required.

It is recommended that a condition of no left-turn phasing be replaced by a phase that provides some left-turn protection when any one of the following conditions exist:

1. An accident problem exist with three or more left-turn related accidents per year occurring at any one approach with no left-turn phasing and the ratio of volume to opposing speed is met.
2. The sight distance available for left-turning vehicles is restricted based on the posted speed limit for opposing traffic. Protected only phasing is recommended.

3. An accident problem exists with six or more left-turn accidents occurring within a 2-year period at any one approach without left-turn phasing.
4. The volume cross product (the product of the left-turn peak hour volume and the opposing through traffic volume divided by the number of opposing lanes) exceeds 50,000.
5. Delay of left-turning vehicles results in a wait in excess of two signal cycles during the peak hour.

Level 2. Protected/Permitted Left-Turn Phasing or Protected Only Phasing Required.

The more restrictive protected only left-turn phasing is recommended when any one of the following conditions exist:

1. The sight distance available for left-turning vehicles is restricted.
2. There are three opposing lanes of traffic and the speed of opposing traffic is equal or exceeds 45 mph.
3. The left-turning volume exceeds 320 vph and the percent of heavy vehicles turning left exceeds 2.5 percent of the left-turning traffic.
4. The opposing volume exceeds 1,100 vph and the percent of heavy vehicles turning left exceeds 2.5 percent of the left-turning traffic.
5. Four or more left-turn accidents in one year or six or more left-turn accidents have occurred in two years on an approach with protected/permitted phasing.
6. If any of the following conditions are satisfied:
   a. Peak 15-minute flow for the left-turning traffic exceeds 320 vph.
   b. Peak 12-minute flow for the opposing traffic exceeds 1,100 vph.
   c. Opposing speed limit is 45 mph or greater.
   d. Double or more left-turn lanes are provided.

Unless one of the criteria is met, use a protected/permitted phase.

Cottrell, B. H.; " Guidelines for Protected/permitted Left-Turn Signal Phasing," Transportation Research Board Record 1069, 1986.

Guidelines for the use of protected/permitted (P/P) left-turn signal phasing were developed by collecting and analyzing data on traffic and roadway conditions for the three types of left-turn phasing. The following left-turn signal guidelines were produced:

1. Volume
   Use P/P phasing when left-turn volume exceeds two vehicles per cycle during

the peak hour, and the peak-hour product of left-turning and opposing volumes divided by the number of opposing lanes is between 50,000 and 200,000.

2. Left-Turn Accidents
   An investigation should be conducted if, at a P/P site, the number of annual left-turn accidents is greater than five, and the critical accident rate based on a mean of 32.6 accidents per 100 million left-turn and opposing volume is exceeded.

3. Traffic Conflicts
   Conduct an investigation if, at a P/P site, the number of total left-turn conflicts in the total period exceeds 39 (4.5 hours during the off-peak and the two-hour peak period), and the total left-turn conflict rate is greater than the critical rate based on a mean of 4.0 left-turn conflicts per 100 left turns.

4. Left-turn Delay
   A P/P phasing should be considered when the mean peak-hour delay per left-turning vehicle exceeds 35 veh sec/veh and the peak-hour left-turn delay exceeds 2.0 veh/hr.

5. Site Conditions
   P/P phasing should be considered if all of the following exist:
   a. adequate sight distance,
   b. no more than two lanes of opposing through traffic,
   c. intersection geometrics do not promote hazardous conditions, and
   d. good access management.

6. Delay-Accident Trade-off
   If P/P phasing is suggested by all the guidelines except accidents, consider P/P if the annual P/P delay savings is greater than or equal to the annual PO accident savings; otherwise use a PO phasing.

7. Traffic Engineering Judgement
   Traffic engineering judgement should be used in conjunction with the guidelines.

Datta, T. K.; "Head -On, Left-Turn Accident at intersections with Newly Installed traffic Signals," Transportation Research Board Record 1318, 1991.

Installation of traffic signals at intersections can be associated with the changes in the accident characteristics at those sites. Past studies show a decrease in the severity of accidents but an increase in accident frequencies. The focus of this study was head-on, left-turn accidents at intersections. The results showed an 80 percent increase in this type of accident when a left-turn lane was provided. This could be related to higher left-turn volumes at locations with an exclusive left-turn lane and that Michigan will rarely include a left-turn phase when traffic signals are first installed. The rate of accidents at intersections where no exclusive left-turn lane was provided was insufficient and needs more study.

Etelamaki, G. R.; "When Is Left-Turn Phasing Justified?," ITE Journal, February 1982.

The decision to install left-turn phasing is sometimes difficult to justify from an engineering stand point. The lack of meaningful warrants and cost/benefit measurements has contributed to this problem. It is intuitive that overall delay and fuel consumption increase with left-turn phasing, but the increases have been difficult to measure. Two different studies (by Kentucky and Michigan DOT) concluded that accident rates, as well as fuel consumption, have a role in warranting left-turn phasing. The warrants should optimize the delay and minimum fuel consumption without compromising safety. Such specific guidelines can be found in other reports.

Fairfax, B.W.; "Methods of Signalizing Left-turn Movements at Channelized Intersections," Traffic Engineering, May 1967.

The purpose of this study was to determine what type of signal indication, shown to the left-turning traffic, will convey to the driver two facts: 1) that he may make the left turn and 2) that he must yield to the opposing traffic. A flashing amber was the most favorable. The traffic accident data reinforce the position that drivers intending to make left turns at flashing amber installations are more cautious than those at other signalized intersections.

Fambro, D. B.; Gaston, G. D.; and Hoff, C. M; "Comparison of Two Protected-Permitted Lead-Lag Left-Turn Phasing Arrangement," Texas Transportation Institute, Report No. TX-91/0989-1F, 1991.

This report studied the operations of "Dallas phasing" which is a special type of lead-lag left-turn phasing developed by traffic engineers in Dallas, Texas. It allows an opposing permitted phase while the other phase is protected and through traffic has a green. The results of this study indicate that the Dallas phasing resulted in similar behavior by left-turning drivers when compared to behavior during other types of permitted left-turn phasing. This phasing resulted in less delay for both left-turning and through movements than the standard phasing set forth in the MUTCD. This phasing offers an operationally efficient alternative at high volume intersections where protected-permitted left-turn phasing is beneficial from a capacity standpoint, and lead-lag left-turn phasing is necessary from a progression standpoint.

This report also presented new values for several parameters used in protected-permitted left-turn models. The following are recommendation parameters when modeling protected-permitted left turns on high type arterial streets with two and three opposing lanes: a) critical gap = 5.1 seconds , b) left-turn headway = 2.5 seconds, and c) number of sneakers = 1 per cycle.

"Guidelines for Signalized Left-Turn Treatments," Federal Highway Administration, Implementation Package, FHWA-IP-81-4, November 1981.

The objectives of this project were to develop and present guidelines for selecting the appropriate left-turn treatment to implement at a signalized intersection. The alternatives may be divided into three basic categories: unprotected left-turn phasing, protected left-turn phasing, and protected/permitted left-turn phasing.

The following guidelines are for the need for protected-only left-turn phasing.

Volume

1. If the left-turn demand to capacity ratio is less than 0.7, a protected-only left-turn phase is probably not needed.
2. If the left-turn demand to capacity ratio is between 0.7 and 0.9, a protected-only left-turn phase may be needed. Accident and operating experience should be carefully reviewed.
3. If the left-turn demand to capacity ratio is greater than 0.9, a protected-only left-turn phase is probably needed.

Accidents

1. Two or less left-turn accidents in a recent twelve-month period indicates that a protected left-turn phase is probably not needed.
2. Three or four left-turn accidents in a recent twelve-month period indicates that the need for a protected only left-turn phase is marginal and should be considered in light of delay and queue length studies.
3. Five or more left-turn accidents in a recent twelve-month period indicates that a protected only left-turn phase is probably needed.

4. Eight or more left-turn accidents in any recent twenty-four month period would indicate that there is a 90 percent chance of an average of five left-turn accidents per year; therefore, a protected only left-turn phase is probably needed.

If the analysis indicates that an approach to a signalized intersection falls into the marginal problem area for both congestion and safety, an exclusive left-turn phase is probably needed. If one problem only is marginal, a protected-only left-turn phase is probably not needed.

Hanson, A. and Dey, D.W.; "A Study of Protected/permitted Left-Turn Signal Operation in the City of Anaheim," Institute of Transportation Engineers.

This report was prepared to present the findings of a study of the effects of protected/permitted phasing in the city of Anaheim. The study found that P/P left-turn phasing reduced vehicle delay and was most efficient at intersections operating at low or medium capacity levels. Two types of intersections were identified where this type of signal intersection could create safety problems. These are intersections which operate at or near capacity, and intersections in areas where drivers may not understand the signal operation. Use of a "Left Turn on Green Ball" sign was recommended.

Hawkins, H. E.; "A Comparison of Leading and Lagging Greens in Traffic Signal Sequence", Institute of Traffic Engineers, Proceedings, 1963.

The recommended signal indication is a green arrow with a circular green during the lead or lag interval. Other methods are used by some organizations, such as a circular green, flashing circular green or flashing amber. A clearance interval between the leading green interval and the opposing straight though movement is seldom used, but has great merit in reducing vehicle conflict. The clearance interval could consist of dropping the green arrow approximately two to three seconds before the exhibition of a circular green to the opposing traffic.

Hummer, J. E.; Montgomery, R. E.; and Sinha, K. C.; " Motorist Understanding of and Preferences for Left-Turn Signals," Transportation Research Board Record 1281, 1990.

A survey of licensed drivers was conducted in Indiana to determine motorist's understanding of and preferences for left-turn signal alternatives. The results showed that the protected signal was by far the best understood, whereas the protected/permitted (P/P) was the most often misunderstood. The "Left Turn Yield on Green" sign proved more confusing than the other P/P sign conditions tested, including the no sign condition.

Among signals, protected-only phasing was most often preferred, and permissive phasing proved the least popular. For many reasons, the leading sequence was preferred by more respondents than the lagging sequence.

Hummer, J.E.; Montgomery, R. E.; and Sinha, K. C.; "Guidelines for Use of Leading and Lagging Left-Turn Signal Phasing," Transportation Research Board Record 1324, 1991.

The study was conducted to develop a set of guidelines for when to use leading or lagging protected/permitted phasing. Signal sequences were evaluated in Indiana using a survey of licensed drivers, an examination of traffic conflicts, an analysis of accident records, and a simulation model of traffic flow. The following guidelines were developed as a result of these actives:

1. In coordinated signal systems, use should be made of any phasing sequence on a particular approach that will maximize the through bandwidth.
2. Lagging, instead of leading, phase sequences should be used at isolated signals serving heavy pedestrian traffic.
3. Lagging, instead of leading, phase sequences should be used at isolated diamond interchanges or one-way pairs.
4. Permissive/protected signals should be used instead of protected/permitted signals where there is a history of, or a potential for, opposing left-turn accidents but where protected-leading or lagging-protected-only signals are not feasible.
5. Permissive/protected signals should be used instead of protected/permitted signals at isolated intersections with four approaches if the signals are fixed-time or incapable of overlapping phases.
6. Intersections where one approach has permissive left turns and the opposing approach has a lagging sequence must be checked for the possibility of trapping. If trapping is possible, the phasing should be changed to eliminate the permissive turn. This can be accomplished by eliminating the lagging sequence, by ensuring that the opposing approaches both have lagging sequences with left-turn phases that begin simultaneously, or by using some other some other phasing.
7. At intersections where the above guidelines do not fully answer the question of lead or lag, the existing phase sequence should not be changed or, if the signal or left-turn protected phase is new, the phase sequence which is most common at similar sites in the area should be used.

Lalani, N.; Cronin, D.; Hattan, D.; and Searls, T.; "A Summary of the Use of Warrants for the Installation of Left-Turn Phasing at Signalized Intersections," ITE Journal, April 1986.

The Colorado/Wyoming Section of ITE prepared a report giving current techniques used to warrant left-turn phasing. The report did not include development of new techniques. The objective was to develop a standard based on the different responses to their questionnaire.

The committee sent 1,200 questionnaires to state and local agencies across the United States as well as Canada, Australia, Europe, Africa, the Middle East, and Asia. Approximately 300 questionnaires were returned. The questions were targeted to determine if a warrant system was being used, what type was used, and their opinion of a nationally established system. The committee recommended that nationally recommended techniques be developed to determine when left-turn phasing is needed at signalized intersections. The most common criteria found were accidents (three to five accidents per year), combination of left-turn and opposing volume (cross product of left-turn and opposing traffic of 30,000 to 50,000 for two-lane road and 50,000 to 100,000 for four-lane road, and left-turn volume (50 to 100 left turns per hour).

"Leading and Lagging Greens in Traffic Control," Traffic Engineering, April 1966.

This paper addressed whether a leading green interval will permit greater traffic volumes through a traffic signal compared with a lagging green interval, with all other factors remaining the same. A survey showed 47.5 percent of the traffic engineers preferred a leading, 32.5 percent preferred a lagging green interval, while 20 percent have no preference and utilize both of the methods equally. While there were no recognized warrants, guidelines for left-turn intervals included eight to ten percent left turns on an approach, left turns exceeding ten percent of opposing through volume, and accident and delay problems.

Lee, J. C.; Workman, R. H.; Hook, D. J.; and Pope, M. J; "Operational Comparison of Leading and Lagging Left Turns," Transportation Research Board Record 1421, 1993

The study was a field comparison between leading and lagging phasing. It was found that the intersection delay was significantly greater with the lagging left-turn operation. Significantly greater delay per approach vehicle occurred with lagging operation than with leading operation for the time periods tested. There were no statistically significant differences in stops, delay, or travel time with the different operating conditions.

"Left-Turn Phase Design in Florida," Florida Section, Institute of Transportation Engineers, ITE Journal, 1982.

The Florida Section of ITE conducted a study to determine the proper use of left-turn phasing. This report includes a literature review, field studies, and professional opinions. The literature review listed three previous reports written by Kentucky, Maryland and California.

Before and after accident statistics were compiled at 28 intersection approaches where changes were made in the type of left-turn phasing (17 of the approaches were changed from protected only to protected/permitted and 11 were changed from protected/permitted to protected only). Results showed that the change to protected/permitted left-turn phasing is not always accompanied by a large increase in left-turn angle accidents. At most of the approaches studied, there was only a small change in the number of annual left-turn angle accidents. Data indicate that a change to protected- only phasing can sometimes produce a dramatic decrease in left-turn angle accidents. The introduction of protective/permissive left-turn phasing resulted in a 40 percent reduction in left-turn delay and a 24 percent reduction in opposing through traffic delay.

The advantages of protected/permitted left-turn phasing, when compared to protected-only left-turn phasing, are:

1. reduces left-turn and overall intersection delay,
2. increases intersection capacity,
3. preserves the flexibility to selectively skip the left-turn phase,
4. provides type of phasing that drivers prefer,
5. prevents left-turn drivers from becoming trapped at actuated phases,
6. allows for use of lower cycle lengths for pretimed signals, and
7. results in less chance of disruption to adjacent through lanes.

The following guidelines should be used to select the type of left-turn phasing:

1. Protected/permitted left-turn phasing should be provided for all intersection approaches that require a left-turn phase unless there is a compelling reason for using another type of left-turn phasing.

2. Protective-only left-turn phasing should be provided for an intersection approach if any of the following conditions exist:

a. double left-turn lanes exist,
b. intersection geometries force use of an exclusive signal head for the left-turn lane,
c. sight distance to opposing traffic is less that 250 feet when opposing traffic is traveling at 35 mph or less, or less than 400 feet when speed is 40 mph or more, or
d. the approach is the lead portion of a lead/lag intersection phasing sequence.

3. Protective-only phasing might be appropriate for an intersection approach if any of the following exist:
   a. poor sight distance to opposing traffic,
   b. speed limit of opposing traffic is higher than 45 mph,
   c. left-turn traffic must cross three or more lanes of opposing traffic,
   d. protected/permitted is currently being used and there is more than six left-turn accidents on an approach, and
   e. unusual intersection geometrics make left turn confusing.

4. Permissive/protected left-turn phasing can be used effectively for some intersection approaches. However, use of this type of phasing should be restricted to only the following situations:
   a. an approach to a T intersection, where opposing U-turns are prohibited,
   b. an approach to a 4-way intersection where the opposing approach has prohibited left turns or protected only left turns, and
   c. opposing approaches to a 4-way intersection where the left-turn volumes from the opposing approaches do not vary throughout the day.

5. Split phasing can be used if any of the following conditions apply:
   a. opposing approaches are offset to an extent that simultaneous left turns would be impossible,
   b. left turn volumes are extremely heavy on opposing approaches and both are nearly equal to the adjacent through movement, and
   c. drivers are permitted to turn left from more that one lane, but drivers are permitted to also use the right-most left turn lane as a through lane.

The recommendation was made that the 5-section cluster be used for protected/permitted left-turn phasing. The proper location of the 5-section cluster is centered over the lane line between the left-turn lane and the left-most through lane. Use of a warning sign on a permanent basis was not recommended.

"Left-Turn Signal Warrants," Southern Section, Institute of Transportation Engineers, Technical Council Committee 76-1, January 1978.

The objective of this study was to develop warrants for the installation of left-turn phasing. Three major types of input were used to achieve the objective: review of literature, questionnaire, and collected field data. There was an expressed opinion that warrants should be developed, but these warrants should not be absolute.

Data collected showed that the minimum left-turn volume to warrant a left-turn phase was 100 to 125 vehicles per hour or two vehicles per cycle. An accident warrant would be when four or more accidents occur in one year on an intersection approach or six or more occur in a two year period. A valid volume warrant would include a combination of left-turn and opposing volume by number of opposing lanes. For one opposing lane, use either a product of 45,000 or sum of 500. For two opposing lane, use either a product of 90,000 or sum of 900. For three opposing lanes, use either a product of 135,000 or sum of 1,000. The left-turn delay, given in vehicle hours could be used with a range of 1.5 to 2.0.

Protected/permitted phasing had widespread use and was generally preferred over exclusive phasing. Generally, a five-section signal head was used for leading phasing. A four-section head was typically used at permissive/protected locations. There was no agreement on the need for special signing.

Lin, F.; "Left-Turn Signal Phasing for Full-Actuated Signal Control," Transportation Research Board Record 1324, 1991.

This study used computer simulation to aid in the understanding and assist in the choice between permissive phasing and protected/permitted phasing for signal control. The important factors concerning such a choice include left-turn volume, opposing volume, the number of opposing lanes, length of left-turn bay, and the volume of cross traffic.

In modeling this simulation, data were used from four intersections at six hour flow patterns. The analysis performed in the study was based on the following conditions:

1. Left-turn drivers have a critical gap of 5 sec.
2. There is a 15 percent chance that the first left-turn vehicle in a queue will turn in front of the first opposing vehicle immediately after the green light is turned on.

When the opposing volume is very heavy, left turns can be made only in the first few seconds after the green onset or after the change begins. The simulated number of such turns varies from one cycle to another. The average is approximately two vehicles per cycle.

The conclusion was that the choice between permissive and protected/permitted phasing is governed primarily by left-turn volume, opposing volume, the number of opposing lanes, and the level of cross traffic. Protected/permitted phasing is generally preferred to permissive phasing if the intersection capacity cannot accommodate signal operations with permissive phasing but is still adequate to support operations with protected/permitted phasing.

Machemehl, R. B. and Mechler, A. M.; "Comparative Analysis of Left-Turn Phase Sequencing," Center for Transportation Research, University of Texas, January 1984.

The Texas Simulation Model was used to study the effects of various left-turn sequence patterns on traffic operations in order to establish guidelines for utilization of most typical sequence patterns.

A review of published research findings regarding effects of left-turn phase sequencing found that permissive/protected versus protected-only sequencing produces significant reductions in vehicular delay while abnormally high accident experiences have been historically attributed to permissive/protected left-turn sequencing. Experiences in five states indicate, however, that permissive phasing does not produce statistically significant changes in accident experience or accident severity at locations with good geometrics and approach speeds less than 45 mph.

The experiments based on delays, accidents, and conflicts compared a wide variety of left-turn phase sequencing patterns. Based upon these analyses, the following findings were developed:

1. From a traffic operations perspective, provision of permissive left turns during the through green will always be beneficial regardless of the type of signal control or left-turn sequence pattern. Only in situations where safety concerns are an overwhelming influence should permissive left turns be prohibited. Data published indicate that safety problems associated with permissive lefts are frequently not severe. Intersection approach speeds in excess of 45 mph are frequently cited as a reason for prohibiting permissive left turns.

2. There is no operational difference between dual leading and dual lagging sequences when permissive left turns are prohibited. When permissive turning is allowed, leading sequences produce less vehicular delay.

3. Split left-turn sequence patterns tend to produce less vehicular delay where critical left-turn and through movements occur on the same approach.

"Manual on Uniform Traffic Control Devices," U.S. Department of Transportation, Federal Highway Administration, 1988.

Specific warrants are not given for when to install left-turn phasing. Possible arrangements of lenses in signal faces are given along with the number and location of signal faces. It was noted that, in a left-turn phasing operation when the protected mode and the permitted mode can occur during the same cycle, a separate signal face is not required for the left turn, but, if provided, shall be considered an approach signal face, and shall meet certain requirements. The requirements are that: 1) during the protected left turn movement, a green arrow shall be displayed simultaneously with a circular red or circular green on the same approach with the protected left turn and simultaneously with a circular red for traffic on the opposing approach, 2) during the permitted left-turn movement, all signal indications on the approach shall display the circular green indication, and 3) all circular indications of the same color facing through motorists as well as left turn motorists shall be simultaneously illuminated. It was noted that no information sign is necessary but, if used, it shall say "Left Turn Yield on Green (symbolic green ball)" (R10-12).

Mattais, J. S. and Upchurch, J. E.; "Left-Turn Signal Warrants for Arizona," Arizona State University, Report Number FHWA/AZ 85/192, June 1985.

A warrant was developed to choose the appropriate type of left-turn signal phasing (permissive, exclusive/permissive, or exclusive). The developed warrants chooses the type of left-turn phasing based on left-turn volume, opposing volume, number of opposing lanes, cycle length, approach speed, sight distance restrictions, and accident history.

Listed below are the important points of information which directly influenced the warrant that was developed.

1. If the left-turn demand in the peak hour is greater than two vehicles per cycle, then either exclusive or exclusive/permissive phasing is required to accommodate left turns.

2. For intersections with two opposing lanes:
   a. permissive phasing works well when the hourly volume cross product is less than 144,000;
   b. exclusive/permissive phasing significantly reduced left-turn delay (as compared to permissive phasing) when the hourly volume cross product exceeded 144,000, and
   c. exclusive/permissive phasing resulted in significantly less left-turn delay than exclusive phasing at all volume levels.

3. For intersections with three opposing lanes:
   a. permissive left-turn phasing works well when the hourly volume cross product is less than 100,000 and
   b. above a volume produce of 100,000,exclusive phasing results in the lowest left-turn delay.

4. Other agencies recommend that exclusive phasing, rather than exclusive/permissive phasing, be used when left-turning traffic must cross three or more lanes of opposing through traffic.

5. Similarly, it is suggested that exclusive phasing, rather than exclusive/permissive phasing, be considered when the speed limit of opposing traffic is greater than 45 mph.

6. Restricted sight distance to opposing traffic creates potential accidents such that exclusive phasing should be used when sight distance is less than 250 feet for speeds of 35 mph or less and 400 feet for speeds greater than 35 mph.

McKay, B.W.;"Lead and Lag Left-Turn Signals," Traffic Engineering, April 1968.

This report compared the use of leading and lagging left-turn signals. It concluded that exclusive left-turn lanes should not be used where there is not a problem of excessive delays. It also stated that exclusive left-turn phasing is not needed unless there are more than two left-turn vehicles per cycle during the peak hour. A lead left-turn sequence should be handled by a separate lane signal and an exclusive lane. A lag sequence should require prohibiting the opposing left turn for safety reasons.

"MUTCD Requirements for Signal Displays to Left-Turning Drivers," ITE Journal, September 1992.

This paper discussed the MUTCD requirements for the different modes of operation of left-turn phasing. It was noted that the provision of consistent, nationally uniform and understandable left-turn displays is a goal that has been difficult to achieve. The most widely used display complying with the MUTCD requirements for the permitted and protected mode is to make one of the two required primary signal faces for the approach a five-section signal face (circular red, yellow, green, plus yellow and green arrow) and locate it over the lane line between the left-turn lane and the adjacent through lane.

General notes relating to all displays are that the green arrow indication must not allow movement conflicting with a "walk" or "flashing don't walk" indication, minimum of two signal faces for the approach, use of supplemental signal faces where needed, placing the signal faces between 40 and 150 feet from the stop line and within 40-degree visibility cone, minimum of eight foot separation between signal faces for through traffic, and locate overhead-supported signal faces in line of drivers' normal view.

Nemeth, Z.A. and Mekemson, J. R.: "Guidelines for Left-Turn Treatments at Signal Controlled Intersections," Ohio State University, Report FHWA-OH-83-003, June 1983.

This study used computer simulation and field studies to evaluate the need for left-turn bays and phasing. If the degree of saturation for the left- turn movement is less than 0.7 then a left-turn phase is probably not justified because of delay while it should be considered when the degree of saturation is above 0.9. Left-turn phase additions almost always increase overall delay at the intersection while the increase in delay can be minimized by the investigation of various left-turn phase options. As compared to the protected/permitted operation, the protected-only left turn phase has an accident rate only half as large. This increase in safety, however, is not gained without a loss in efficiency. A protected/permitted left-turn phase has a greater capacity and thus lower delay not only for the left turn movement, but also for the entire intersection.

Perfater, M. A.; "An Assessment of Exclusive/Permissive Left-Turn Signal Phasing," Virginia Highway and Transportation Research Council, March 1982.

The purpose of this study was to assess the performance of E/P left-turn signal phasing in Virginia. The findings from the study led to the following recommendations.

1. In order to establish firm guidelines for the installation of E/P left- turn phasing at new 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.

3. A supplemental regulatory traffic signal sign should be used.

4. Advance publicity should precede the installation of E/P signals.

Perfater, M. A.; "Motorists' Reaction to Exclusive/Permissive Left-Turn Signal Phasing," Virginia Highway and Transportation Research Council, March 1982.

Intersection characteristics and accident data were gathered at ten intersections with exclusive/permissive phasing. The results showed an increase in left-turn accidents after installation of exclusive/permissive phasing. The study also involved a survey on how the motorists felt about exclusive/permissive left-turn phases. The results showed that about 36 percent of the motorists were confused the first time they passed through an intersection. After a period of adjustment, over 70 percent were in favor of them. The opinion was that instructive signs helped motorist adjust.

"Recommended Warrants for the Use of Protected/permitted Left-Turn Phasing," Institute of Transportation Engineers, Technical Council Committee 4A-30, September 1993.

The purpose of this report was to evaluate and summarize the criteria and guidelines used by various operating agencies, and to propose nationwide warrants for consideration by the ITE Technical Council.

If all of the listed conditions are met and any of the warrants are also met, protected/permitted left-turn phasing should be considered. However, the guidelines for installation should be followed.

Conditions

1. The minimum left-turn demand should be greater than two vehicles per cycle during the peak hour.
2. There should not be more than one left-turn lane.
3. The maximum number of opposing through lanes is three.
4. The opposing through speed limit should be less than or equal to 45 mph.
5. The sight distance should be adequate.

Warrants

1. Accident Experience
   Satisfy either:
   a. The number of left-turn accidents is fewer than 6 per year.
   b. The left-turn accident rate is less than 32.6 accidents per million vehicles.

2. Delay
   Satisfy either:
   a. Mean peak hour delay per left-turning vehicle exceeds 35 veh.-sec.
   b. Total peak hour left-turn delay exceeds 2 veh.-hr.

3. Volume
   The cross product of peak-hour volume for the conflicting movement should be in the range of 50,000 and 200,000.

Guidelines

1. Left-turning traffic should not have a separate signal head. A shared signal head for both through and left-turn traffic should be located above the line separating the left-turn lane from the adjacent through lane.

2. Lens arrangement "s" in MUTCD (cluster head on mast-arm) should be used when the left-turn phase is leading;
3. Lens arrangement "m" (vertical head) should be used when the left- turn phase is lagging;
4. Special regulatory sign, R10-12 in MUTCD, should be used in the following situations:
   a. during the transition period when changing from protected-only to protected/permitted phasing;
   b. when signal head placement is such that the driver may not otherwise understand the meaning of the green ball;
   c. where accident or traffic conflict experience indicates a problem with compliance.

"Report on Protected/permitted Left Turns," Lexington Fayette Urban County Government, January 1991

The study was conducted on six intersections in Lexington where protected/permitted left-turn phases were installed. The results showed there was no dramatic increase in left-turn accidents. A highway capacity analyis showed a 50 percent reduction in left-turn delays and a 24 percent reduction in overall intersection delays. It was noted that the protected/permitted signal head seems to curtail running of red lights at protected-only locations where a vehicle has to wait with no oncoming traffic.

Rorabaugh, T. and Mohle, R. H.; "Queue Dection Logic and Phasing for Leading Protected/permitted Left-Turn Signalization," ITE Techical Notes, December 1977.

The purpose of this paper was to provide information on a) the utilization of a queue detection logic to determine when the green arrow or protected left-turn signal phase should be operated with the "leading green" mode and b) the possible "trap" when the full actuated one-way lagging mode is employed at a cross intersection.

Based on the observations made at the experimental intersection, utilization of the queue detector concept in conjuction with the two-way leading "protected/permitted" left-turn signalization scheme provides a more rational means of determining when a protected turning movement is needed.

Rouphail, N. M; "Analytical Warrant for Separate Left-Turn Phasing," Transportation Research Board Record 1069, 1986

The development of a new volume warrant for left-turn phasing at signalized intersections was presented. The concept is to maintain a fixed volume-to-capacity (v/c) ratio for all intersection movements. Left-turn phasing would be warranted when the unprotected left-turn v/c ratio exceeds that of through traffic. A left-turn volume warrant is proposed using a formula which considers opposing volume, left turn capacity, through lane capacity, effective green time, Webster's optimum cycle length, lost time per cycle, unprotected left-turn saturation flow rate, unopposed left-turn saturation flow rate, and effective green time.

Rouphail, N. M. and Radwan, A. E.; "Simultaneous Optimization of Signal Setting and Left-Turn Treatments," Transportation Research Record Number 1287, 1990.

The report addressed two apparent weaknesses in current signal-setting methods involving the inability to determine the optimal number of phases and the alternative phase treatments for left-turn movements in each of these phases. The method described determines the optimal cycle length, splits, and left-turn phasing (permissive or permissive-protected) that satisfy a maximum v/c ratio constraint for each movement.

Shebeeb, O.; "Safety and Efficiency for Exclusive Left-Turn Lanes at Signalized Intersections," ITE Journal, July 1995.

This study examined the safety and efficiency of left-turn movement at signalized intersections. It is based on left-turn accident data in three consecutive years and the average delay per vehicle in the peak-hour period. The study's purpose was to attempt to develop models that capture potential trade-offs between left-turn efficiency and safety.

Statistical tests produced the following results:

1. no significant difference was detected in efficiency or in safety between lead and lag operations for protected-only phasing, protected/permitted phasing or Dallas phasing,
2. while protected-only phasing is significantly less efficient than protected/permitted, it is significantly safer,
3. protected-only phasing is significantly less efficient than Dallas phasing, but there is no significant difference in safety between the two phasing types,

4. statistical comparisons do not show significant difference in efficiency or in safety between proteced/permissive phasing and Dallas phasing,
5. Dallas phasing resluts in fewer accidents compared to conventional protected/permitted phasing since it is specifically designed to eliminate the yellow trap problem,
6. permissive-only phasing is more efficient than protected/permitted, but there is no significant difference in safety between the two phasing types, and
7. a definite trade-off exists between left-turn accidents rates and left-turn stopped delays.

"Signal Displays for Protected/permitted Left-Turn Phasing," Southern California Section, Institute of Transportation Engineers, January 1984.

The purpose of this report was to establish guidelines for a uniform display for protected/permitted left-turn phasing. The committee felt that there was little question concerning the advantages of the use of protected/permitted (P/P) left-turn phasing from the standpoint of reductions in traffic delay. The findings of this report suggest that the use of the "cluster" head configuration for the mast arm display may be appropriate as a national standard.

The following are the main results of the study:

1. P/P left-turn phasing is being used by many agencies,
2. significant vehicle delay savings can be realized with P/P left-turn phasing compared to fully protected left-turn phasing,
3. P/P left turn phasing is not an accident reduction technique,
4. left turn accident rates with P/P are comparable to those experienced under normal two-phase operation,
5. there is a need for continuing driver education,
6. advisory signs appear unnecessary,
7. cluster signal heads on mast arms, coupled with lateral separation distinctive from fully protected left-turn signal displays, are effective and may enhance motorist recognition of the P/P function, and
8. the left-turn arrow shall not be allowed to lag except at "T" intersections or where the opposing left turn approach gets a simultaneous green arrow indication.

Spitz, S.; "Left Turn Phases - Who Needs Them?," Traffic Engineering, December 1974.

This study evaluated guidelines to consider for left-turn phasing. It was recommended that left-turn phasing should only be considered as a solution to a problem and only after less restrictive measures have been considered. The two most common problems (excessive left turn collisions and excessive left-turn delay) should be determined by real measurement. The product of left-turn and opposing volume should not be used to indicate need for left-turn phasing.

Stonex, A. and Upchurch, J. E., "Conversion from Permissive to Exclusive/Permissive Left-Turn Phasing: A Before-and-After Evaluation," Transportation Research Board Record 1114, 1987.

A before-and-after study was conducted to determine the effects of converting left-turn signal phasing from a permissive condition to an exclusive condition. The results showed that left-turn volumes increased significantly in the after phase. The percentage of vehicles that stopped increased from 43 percent to 71 percent. Average delays to through traffic more than quadrupled in the after phase in one direction and more than tripled in the other direction. Average delay to left-turn vehicles decreased a small amount. The conversion resulted in 87.9 veh-hr of additional delay per day. This delay converts to a cost of $398,587/year in additional vehicle operating, travel time, and emissions cost. The improvements in processing left-turn vehicles were obtained at the expense of inconveniencing the through movement.

Traffic Control Devices Handbook, U.S. Department of Transportation, Federal Highway Administration, 1983.

The left-turn phase criteria suggested are a combination of left-turn phasing warrants used in several states, and the results of research in this area. The warrants are grouped by type:

Volume
1. the product of left-turn vehicles and conflicting through vehicles during the peak hour is greater than 100,000,
2. as above, with the product greater than 50,000,
3. left-turn volume greater than 100 (or 90) vehicles during peak hour,
4. left-turn peak period volumes greater than two vehicles per cycle per approach still waiting at the end of green (for permitted signals), and

5. left-turn volumes greater than 50 vehicles per peak hour when through traffic speed exceeds 45 mph.

Delay
1. delay on left turns greater than two cycles and
2. one left-turning vehicle delayed one cycle or more during one hour.

Accidents
1. Five or more left-turn accidents within a 12-month period.

The following are suggested guidelines for considering separate left-turn phasing on approaches having a separate left-turn lane.

Volumes
1. Consider left-turn phasing when volume exceeds 100,000 on a four-lane street and 50,000 on a two lane street. The left-turn lane volume must exceed two vehicles per cycle.

Delay
1. Install left-turn phasing if a left-turn delay of 2.0 vehicle hours or more occurs in a peak hour. The average delay must be at least 35 seconds per vehicle, and there must be a minimum of two left turns per cycle.

Accident Experience
1. Install left-turn phasing if the critical number of left-turn accidents has occurred. For one approach, the critical number is four left-turn accidents in one year or six in two years. For both approaches, the critical number is six left-turn accidents in one year or ten in two years.

The following are guidelines for protected/permitted left-turn phasing:

1. Where left-turn phasing has been determined to be warranted on a volume basis, consider the use of protected/permitted left-turn phasing before protected only left-turn phasing is implemented.

2. When using leading protected/permitted phasing, consider the use of the left-turn queue detection to improve overall intersection operating efficiency. In general, protected/permitted phasing will be safer than permissive only but will not be as safe as protected only.

Upchurch, J.E.; Radwan, A. E.; and Dean, A.G.; "Development, Evaluation, and Application of Left-Turn Signal Warrants," Arizona Department of Transportation, Report Number FHWA-AZ91-267, August 1991.

This study dealt with five types of left-turn signal phasing: permissive, leading exclusive, lagging exclusive, leading exclusive/permissive, and lagging exclusive/permissive. The report describes the database of Arizona signalized intersections, findings on left-turn accident rates for different types of left- turn phasing, results of a validation study of the TEXAS computer simulation model, and presents a work plan for a future research project.

The following conclusions were made concerning the accident analysis: 1) leading exclusive phasing has the lowest left-turn accident rate, 2) when there are two opposing lanes, lagging exclusive/permissive has the worst accident rate, 3) when there are three opposing lanes, leading exclusive/permissive has the worst accident rate, 4) for two opposing lanes, the order of safety (from best to worst) is leading exclusive, permissive, leading exclusive/permissive, and lagging exclusive/permissive (there is a small difference in the accident rate among the last three types of phasing), 5) for three opposing lanes, the order of safey (from best to worst) is leading exclusive, lagging exclusive/permissive, permissive, and leading exclusive/permissive, and 6) in three out of four cases, accident rates are higher with three opposing lanes (the exception is for lagging exclusive/permissive phasing (although the difference in rates is small). The highest accident rate for any type was for leading exclusive/permissive with three opposing lanes.

Upchurch, J. E.; "Guidelines for Selecting Type of Left-Turn Phasing," Transportation Research Board Record 1069, 1986.

The guidelines presented select the type of left-turn phasing based on left-turn volume, opposing volume, number of opposing lanes, cycle length, approach speed, sight distance restrictions, and accident history.

Data suggest that when there are three opposing lanes of traffic, left turners are much more reluctant to make a turn on a circular green indication. With three opposing lanes, it is more difficult for the driver to see and judge suitable gaps. The driver must check three lanes rather than two, and there is a greater chance that one vehicle will mask out another. A further factor is that with three opposing lanes, longer gaps are necessary because vehicles must cross three lanes instead of two. The guidelines recommend that exclusive phasing be used in this case.

It is suggested that exclusive phasing be considered when the speed limit of opposing traffic is greater than 45 mph. Also, exclusive phasing is to be used when there is restricted sight distance.

Left-turn accident rates (left turn accidents per one million entering left- turn vehicles) were 3.68 for permissive, 2.24 for exclusive/permissive, and 0.97 for exclusive phasing.

A flow chart was developed to determine the type of left-turn phasing. Data required to use the flow chart include: left-turn volume during the peak hour, cycle length, opposing volume during the peak hour, number of opposing lanes, speed of opposing traffic, available sight distance, and accident history. For three opposing lanes, exclusive phasing is recommended if the volume cross product is over 100,000 or if there is restricted sight distance (under 250 feet when speeds are 35 mph or less or under 400 feet when speeds are 40 mph or more) or when there is a severe left-turn accident problem. Exclusive phasing should be considered, for two or three opposing lanes, when the opposing speed is over 45 mph since this indicates a potential left turn accident problem. The sight distance and left-turn accident criteria also apply for two opposing lanes.

Warren, D. L.; "Accident Analysis of Left-Turn Phasing," Public Roads, Vol. 48, No.4, March 1985.

This study examined accident data for intersections where the left-turn phasing was changed from protected to protected/permitted and other locations where the change was from permissive to protected/permitted. The investigation was limited to high-speed signalized intersections with separate left-turn lanes on the treated approaches. The number of accidents before and after the change was analyzed and compared to the number of accidents at similar intersections that were not changed. Accident data were compiled for two years before and after the changes. A total of nine sites was selected in Maryland. At two intersections the protected/permitted phasing replaced a permitted left turn while it replaced protected-only phasing at the other intersections. Each intersection was inspected and information on the number of lanes, median width, signal placement, left-turn signal display, supplementary signing, posted speeds, and sight time was recorded. All the study sites had traffic actuated leading phasing and supplementary signs.

Accidents that occurred on the approach to the intersection (0.2-mile main road, 0.1-mile side road) and that were associated with the intersection were classified as "intersection accidents." Similar periods before and after signalization were compared to avoid seasonal bias.

The total number of accidents increased at only three of the nine intersections but left-turn accidents increased at five intersections. Left-turn accidents included only those accidents involving left-turn vehicles on the approaches where protected/permitted phasing was installed. There was an overall decrease in rear-end accidents at these intersections. These finding strongly suggest that the conversion of intersections from protected-only to protected/permitted phasing altered the distribution of accident type (left turn, rear end, other). The results from this study suggest that accident severity increased with protected/permitted phasing even though total accidents decreased.

At intersections that previously had no left-turn signals, rear-end and total accidents generally decreased, with left-turn accidents showing an increase of less than one per year. At intersections that were converted from protected- only to protected/permitted phasing, rear-end and total accidents decreased, while left-turn accidents increased dramatically. The number of left-turn accidents increased 50 percent and four-fold increases can be expected at some sites.

Williams, J.C.; Ardekani, S. A.; and Asante, S. A.; "Motorist Understanding of Left-Turn Signal Indications and Auxiliary Signs," Transportation Research Board, 1992.

A mail survey was conducted to assess Texas motorists' understanding of left-turn signal indications and accompanying auxiliary signs. Of 6,000 surveys mailed statewide, 894 were returned. The principal conclusions were: a) a green arrow should always be used for protected left turns, rather than a circular green accompanied by a sign, b) a circular red and green arrow should not be shown simultaneously in a five-section signal head, and c) if the red arrow is to be used in Texas, it will have to be accompanied by a public education program.

Wright, C. R. and Upchurch, J.; "Before and After Comparison of Leading Exclusive and Permissive/Exclusive Lagging Left-Turn Phasing," Transportation Research Board Record 1368, 1991.

Three different types of left-turn phasing were compared at an intersection. The phasing alternatives were leading exclusive; leading exclusive/permissive; and permissive/exclusive lagging. In general, substantial reductions in delay occurred for both through and left-turn movements when the change from leading exclusive to leading exclusive/permissive was made; increases in both though and left-turn delay occurred when phasing was changed from leading exclusive/ permissive to permissive/exclusive lagging; and delay under permissive/exclusive lagging operation was less than under the leading exclusive phasing.

Wright, R. S., "Left Turn Signal Display; An Issue Paper on the Left-Turn Phasing Controversy."

The paper analysed motorist's problems with protected/permitted phasing. It was noted that accident frequency is less than with a strictly permissive operation but greater than with exclusive phasing. A conclusion was that the increase in many of the accidents was due to the lack of understanding of this type of phasing and undue risk taking and misjudgement of gaps by left turning drivers. There is a variety of opinion concerning how to correct a misunderstanding of displays. Proposed solutions have included eliminating the exclusive signal head for the left-turn lane and using a five-section cluster as a shared signal for left-turn and through-drivers and use of signing adjacent to the left-turn signal head. It has also been suggested that if a separate signal head is installed for the left-turn lane, then the circular red display should be shut off when the green arrow protected turn interval is engaged. The number and location of signal faces for the protected and permitted mode of left-turn phasing is discussed in the MUTCD. The MUTCD allows the option of having the exclusive left-turn signal and allows the option of signing.

APPENDIX B

INTERSECTION CHARACTERISTICS AND ACCIDENT DATA

CODE SHEET FOR INTERSECTION CHARACTERISTICS AND ACCIDENT DATA

INT.NUM	=	Intersection Number
DIR.	=	Approach Direction
TOT ACC	=	Total Number of Accidents at Intersection
TOT INJ	=	Total Number of Accidents with Injuries at Intersection
TOT LT	=	Total Number of Left-turn Accidents at Intersection
TOT LTI	=	Total Number of Left-turn Accidents with Injuries at Intersection
AVG YR	=	Average Number of Left-turn Accidents per Year
SL	=	Speed Limit
LT LANE	=	Number of Left-turn Lanes
OPP LANE	=	Number of Opposing Through Lanes
PHT VOL	=	Peak Hour Opposing Through Volume
PHLT VOL	=	Peak Hour Left-turn Volume
PHASING	=	Type of Left-turn Phasing
1	=	Protected Only
2	=	Protected/Permitted
3	=	Permissive Only
LE OR LA	=	Leading = 1 Lagging = 2
Reg Sign	=	Regulatory Sign " Left Turn Must Yield on Green Ball" (R10-12)
1	=	Yes
2	=	No
SIG CON	=	Left-Turn Signal Head Configuation (as Described in Table 4-1 MUTCD)
0	=	C
1	=	M
2	=	S
3	=	None
LT + OPP	=	Left-turn Plus Opposing Volume
LT x OPP	=	Left-turn Times Opposing Volume

INT. NUM	DIR.	TOT ACC	TOT INJ	TOT LT	TOT LTI	AVG YR	S L	LT LANE	OPP LANE	PHT VOL	PHLT VOL	PHASING	LE OR LA	REG. SIG	SIG CON	LT + OPP	LT X OPP
2.1	S	16	13	5	5	1.25	55	1	1	107	71	3	0	2	3	178	7597
2.1	N	16	13	1	1	0.25	55	1	1	78	17	3	0	2	3	95	1326
2.2	S	21	13	1	1	0.25	55	1	1	450	60	3	0	2	3	510	27000
2.2	N	21	13	4	3	1.00	55	1	1	320	90	3	0	2	3	410	28800
2.3	S	6	1	0	0	0.00	55	1	1	102	33	1	1	2	0	135	3366
2.3	N	6	1	0	0	0.00	55	1	1	53	32	1	1	2	0	85	1696
3.1	S	24	13	3	2	0.75	55	1	2	798	77	3	0	2	3	875	61446
3.1	N	24	13	5	2	1.25	55	1	2	454	75	3	0	2	3	529	34050
3.2	S	5	0	1	0	0.25	55	1	2	478	155	1	1	2	0	633	74090
3.2	N	5	0	0	0	0.00	55	1	2	437	39	1	1	2	0	476	17043
3.2	W	5	0	1	0	0.25	45	1	1	150	119	1	1	2	0	269	17850
3.2	E	5	0	0	0	0.00	45	1	1	309	82	1	1	2	0	391	25338
5.1	S	12	2	0	0	0.00	45	1	1			3	0	2	3		
5.1	N	12	2	1	0	0.25	45	1	1			3	0	2	3		
5.1	W	12	2	2	0	0.50	45	1	1			3	0	2	3		
5.1	E	12	2	1	0	0.25	45	1	1			3	0	2	3		
5.2	N	7	2	0	0	0.00	45	1	2	311	204	1	1	2	0	515	63444
5.2	S	7	2	0	0	0.00	45	1	2	779	121	1	1	2	0	900	94259
5.3	N	20	7	0	0	0.00	45	1	2			1	1	2	0		
5.3	S	20	7	0	0	0.00	45	1	2			1	1	2	0		
5.4	N	4	1	0	0	0.00	45	1	2	520	51	1	1	2	0	571	26520
5.4	S	4	1	0	0	0.00	45	1	2	405	47	1	1	2	0	452	19035
5.5	N	19	2	0	0	0.00	45	1	2			1	1	2	0		
5.5	S	19	2	0	0	0.00	45	1	2			1	1	2	0		
5.6	N	12	5	0	0	0.00	45	1	2	381	226	1	1	2	0	607	86106
5.7	S	33	4	1	1	0.25	45	1	2	309	48	1	1	2	0	357	14832
5.7	N	33	4	0	0	0.00	45	2	2	234	407	1	1	2	0	641	95238
5.7	W	33	4	1	0	0.25	45	1	2	441	75	1	1	2	0	516	33075
5.7	E	33	4	0	0	0.00	45	1	2	231	51	1	1	2	0	282	11781
7.1	S	25	9	1	0	0.25	55	1	1	743	238	1	1	2	0	981	176834
7.2	W	28	10	0	0	0.00	45	1	2			1	1	2	0		
8.1	W	23	8	3	2	0.75	55	1	2	452	151	1	1	2	0	603	68252
8.1	E	23	8	1	0	0.25	55	1	2	696	73	1	1	2	0	769	50808
8.2	W	56	22	2	0	0.50	55	1	2	914	119	1	1	2	0	1033	108766
8.2	E	56	22	19	11	4.75	55	1	2	672	82	3	0	2	3	754	55104
8.3	S	20	3	5	1	1.25	35	0	1	108	53	3	0	2	3	161	5724
8.3	N	20	3	0	0	0.00	45	0	1	36	7	3	0	2	3	43	252
8.3	W	20	3	0	0	0.00	55	1	2	210	108	1	1	2	0	318	22680
8.3	E	20	3	0	0	0.00	55	1	2	457	24	1	1	2	0	481	10968
8.4	N	3	1	0	0	0.00	55	1	1	211	62	1	1	2	0	273	13082
8.4	S	3	1	0	0	0.00	55	1	1	78	276	1	1	2	0	354	21528
8.5	S	8	1	1	0	0.25	55	1	2	274	44	1	1	2	0	318	12056
8.5	N	8	1	0	0	0.00	55	1	2	259	104	1	1	2	0	363	26936
8.5	W	8	1	2	1	0.50	45	0	1	160	47	3	0	2	3	207	7520
8.5	E	8	1	0	0	0.00	35	0	1	128	55	3	0	2	3	183	7040
9.1	N	13	10	2	1	0.50	55	1	2	360	45	3	0	2	3	405	16200
9.1	S	13	10	2	2	0.50	55	1	2	372	52	3	0	2	3	424	19344
9.1	E	13	10	0	0	0.00	55	1	1	30	42	3	0	2	3	72	1260
9.1	W	13	10	1	1	0.25	55	1	1	49	40	3	0	2	3	89	1960
10.1	N	10	7	7	4	1.75	55	1	2	689	168	3	0	2	3	857	115752
10.2	S	22	8	4	1	1.00	55	0	2	951	148	3	0	2	3	1099	140748
10.3	W	26	7	1	0	0.25	55	0	1	177	14	3	0	2	3	191	2478
10.3	E	26	7	0	0	0.00	55	0	1	92	451	3	0	2	3	543	41492
10.4	S	17	5	0	0	0.00	55	1	2	603	15	1	1	2	0	618	9045
10.5	E	16	7	0	0	0.00	55	1	2	738	42	1	1	2	0	780	30996
10.5	W	16	7	0	0	0.00	55	1	2	605	103	1	1	2	0	708	62315
10.6	E	12	3	1	0	0.25	55	1	2	939	115	1	1	2	0	1054	107985
10.7	E	23	9	0	0	0.00	55	1	2	799	57	1	1	2	0	856	45543
10.7	W	23	9	0	0	0.00	55	1	2	556	25	1	1	2	0	581	13900
10.8	E	4	1	0	0	0.00	55	1	2	312	32	1	1	2	0	344	9984
10.8	W	4	1	0	0	0.00	55	1	2	432	85	1	1	2	0	517	36720
10.9	E	9	3	0	0	0.00	55	1	2	717	122	1	1	2	0	839	87474

INT. NUM	DIR.	TOT ACC	TOT INJ	TOT LT	TOT LTI	AVG YR	S L	LT LANE	OPP LANE	PHT VOL	PHLT VOL	PHASING	LE OR LA	REG. SIG	SIG CON	LT + OPP	LT X OPP
10.9	W	9	3	0	0	0.00	55	1	2	497	28	1	1	2	0	525	13916
10.10	E	13	4	1	1	0.25	55	1	2	855	89	1	1	2	0	944	76095
11.1	S	9	4	1	1	0.25	55	1	2			1	1	2	0		
11.1	N	9	4	0	0	0.00	55	1	2			1	1	2	0		
11.1	W	9	4	2	0	0.50	45	1	1			1	1	2	0		
11.1	E	9	4	0	0	0.00	45	1	1			1	1	2	0		
11.2	N	1	0	0	0	0.00	55	1	2	778	29	3	0	2	3	807	22562
11.3	N	4	1	0	0	0.00	55	1	2			1	1	2	0		
11.3	S	4	1	0	0	0.00	55	1	2			1	1	2	0		
15.1	S	31	5	2	0	0.50	35	0	1	618	45	3	0	2	3	663	27810
15.1	N	31	5	0	0	0.00	35	1	1	214	109	3	0	2	3	323	23326
15.1	W	31	5	0	0	0.00	35	1	1	229	18	3	0	2	3	247	4122
15.1	E	31	5	7	1	1.75	35	1	1	307	264	3	0	2	3	571	81048
19.1	N	18	3	0	0	0.00	55	1	2	1232	13	3	0	2	3	1245	16016
19.2	S	30	14	8	2	2.00	40	1	2			2	1	2	2		
19.3	S	54	14	8	3	2.00	40	1	2			2	1	2	2		
19.4	N	63	16	12	3	3.00	35	1	2	691	97	2	1	2	2	788	67027
19.5	S	6	3	1	1	0.25	35	1	2			2	1	2	2		
19.5	N	6	3	0	0	0.00	35	1	2			2	1	2	2		
19.6	N	9	3	1	1	0.25	35	1	2			2	1	2	2		
19.7	W	5	2	1	0	0.25	25	1	1			2	1	2	1		
22.1	N	13	4	1	0	0.25	35	1	1	472	94	2	1	1	2	566	44368
22.1	S	13	4	0	0	0.00	35	1	1	460	216	2	1	1	2	676	99360
22.2	N	31	8	2	0	0.50	45	0	2	230	83	3	0	2	3	313	19090
24.1	N	20	10	1	1	0.25	55	0	2	325	33	3	0	2	3	358	10725
24.2	S	34	12	3	0	0.75	55	1	2	278	23	3	0	2	3	301	6394
24.2	N	34	12	0	0	0.00	55	1	2	141	32	3	0	2	3	173	4512
24.2	W	34	12	10	2	2.50	55	0	2	46	87	3	0	2	3	133	4002
24.2	E	34	12	2	0	0.50	55	0	2	73	15	3	0	2	3	88	1095
24.3	S	39	11	1	0	0.25	35	1	2			2	1	1	2		
24.3	N	39	11	4	2	1.00	35	1	2			2	1	1	2		
24.4	S	24	10	6	2	1.50	45	1	2	471	10	2	1	1	2	481	4710
24.4	N	24	10	10	5	2.50	45	0	2	410	133	2	1	1	2	543	54530
24.5	W	15	2	3	0	0.75	35	1	1	350	145	2	1	1	2	495	50750
24.6	S	35	11	9	4	2.25	45	0	2	1057	71	3	0	2	3	1128	75047
24.7	N	26	10	3	2	0.75	45	1	2	520	162	2	1	2	2	682	84240
24.8	N	7	2	1	0	0.25	45	1	2			1	1	2	0		
24.9	N	34	8	3	1	0.75	45	1	2	851	205	1	1	2	0	1056	174455
24.10	S	8	4	1	0	0.25	45	1	2	1046	169	2	1	1	2	1215	176774
24.11	S	24	4	0	0	0.00	35	1	1	375	40	2	1	1	2	415	15000
24.11	N	24	4	0	0	0.00	35	1	1	358	163	2	1	1	2	521	58354
24.11	W	24	4	1	0	0.25	35	1	1	485	69	2	1	1	2	554	33465
24.11	E	24	4	0	0	0.00	35	1	1	456	33	2	1	1	2	489	15048
24.12	S	15	6	1	0	0.25	45	0	1	192	25	3	0	2	3	217	4800
24.12	N	15	6	1	1	0.25	45	0	1	166	37	3	0	2	3	203	6142
24.13	E	8	3	2	0	0.50	45	0	1	626	9	3	0	2	3	635	5634
30.1	W	20	6	0	0	0.00	55	1	1	683	19	3	0	2	3	702	12977
30.1	E	20	6	3	2	0.75	55	1	2	320	187	3	0	2	3	507	59840
30.1	S	39	11	1	0	0.25	35	1	2	52	44	3	0	2	3	96	2288
30.1	N	39	11	0	1	0.00	35	1	2	104	19	3	0	2	3	123	1976
30.2	S	52	15	5	3	1.25	55	1	2	584	33	1	1	2	0	617	19272
30.2	N	52	15	3	1	0.75	55	1	2	593	26	1	1	2	0	619	15418
30.3	S	22	8	8	4	2.00	35	1	2	593	26	3	0	1	3	619	15418
30.3	N	22	8	4	1	1.00	35	1	2	1094	117	3	0	1	3	1211	127998
30.3	E	22	8	0	0	0.00	35	1	1	274	37	2	1	1	1	311	10138
30.3	W	22	8	0	0	0.00	35	1	1	284	73	2	1	1	1	357	20732
30.4	S	25	11	5	4	1.25	35	1	2	903	208	2	1	1	1	1111	187824
30.5	E	44	9	1	0	0.25	35	1	1	554	40	2	1	1	2	594	22160
30.6	W	15	3	0	0	0.00	35	1	1	333	101	2	1	1	2	434	33633
30.7	E	19	6	2	1	0.50	55	1	2	500	76	3	0	2	3	576	38000
30.8	E	26	7	2	0	0.50	55	1	2			1	1	2	0		
30.9	S	29	9	0	0	0.00	35	1	2	954	88	2	1	1	2	1042	83952

INT. NUM	DIR.	TOT ACC	TOT INJ	TOT LT	TOT LTI	AVG YR	S L	LT LANE	OPP LANE	PHT VOL	PHLT VOL	PHASING	LE OR LA	REG. SIG	SIG CON	LT + OPP	LT X OPP
30.9	N	29	9	0	0	0.00	35	1	2	1312	29	2	1	1	2	1341	38048
34.1	S	135	36	11	5	2.75	45	1	2	1542	406	2	2	2	2	1948	626052
34.1	N	135	36	12	6	3.00	45	1	2	1343	284	2	2	2	2	1627	381412
34.2	W	27	14	2	1	0.50	55	1	2	1217	19	3	0	2	3	1236	23123
34.2	E	27	14	4	3	1.00	55	1	2	664	52	3	0	2	3	716	34528
34.3	E	30	11	0	0	0.00	55	1	3	2692	4	1	1	2	0	2696	10768
34.4	W	80	20	0	0	0.00	55	1	3	1740	329	1	1	2	0	2069	572460
34.5	E	53	10	0	0	0.00	55	1	2	1489	203	1	1	2	0	1692	302267
34.6	E	44	15	1	1	0.25	55	1	2	290	138	1	1	2	0	428	40020
34.7	S	24	6	4	1	1.00	55	1	2	2088	23	3	0	2	3	2111	48024
34.7	N	24	6	2	0	0.50	55	1	2	1605	27	3	0	2	3	1632	43335
34.8	S	35	12	0	0	0.00	55	1	2	1791	27	3	0	2	3	1818	48357
34.9	S	12	6	0	0	0.00	55	1	2	1533	131	3	0	2	3	1664	200823
34.10	S	11	3	1	0	0.25	55	1	1	458	38	3	0	2	3	496	17404
34.11	W	21	9	4	3	1.00	55	1	2	776	50	2	1	1	2	826	38800
34.11	E	21	9	0	0	0.00	55	1	2	453	198	2	1	1	2	651	89694
34.12	S	44	13	1	1	0.25	55	1	2	507	554	1	1	2	0	1061	280878
34.12	N	44	13	2	2	0.50	55	1	2	1264	120	1	1	2	0	1384	151680
34.12	W	44	13	1	0	0.25	45	1	2	739	187	1	1	2	0	926	138193
34.12	E	44	13	0	0	0.00	45	1	2	700	136	1	1	2	0	836	95200
34.13	W	46	14	1	0	0.25	55	1	1	204	50	3	0	2	3	254	10200
34.14	W	36	9	5	2	1.25	45	1	2	602	16	2	1	2	2	618	9632
34.14	E	36	9	2	0	0.50	45	1	2	944	176	2	1	2	2	1120	166144
34.15	W	77	20	20	5	5.00	45	1	2	1238	329	2	1	2	2	1567	407302
34.15	E	77	20	13	6	3.25	45	1	2	1042	275	2	1	2	2	1317	286550
34.16	N	133	39	4	0	1.00	45	2	2	1116	372	1	1	2	0	1488	415152
34.16	S	133	39	1	1	0.25	45	2	2	1152	117	1	1	2	0	1269	134784
34.16	E	133	39	20	8	5.00	45	1	2	790	286	2	1	2	2	1076	225940
34.16	W	133	39	26	11	6.50	45	1	2	1515	461	2	1	2	2	1976	698415
34.17	N	45	8	2	0	0.50	35	1	1	134	151	2	1	2	2	285	20234
34.17	S	45	8	1	0	0.25	35	1	1	173	89	2	1	2	2	262	15397
34.17	E	45	8	0	0	0.00	45	1	2	996	183	1	1	2	0	1179	182268
34.17	W	45	8	3	2	0.75	45	1	2	1405	82	1	1	2	0	1487	115210
34.18	E	84	20	17	4	4.25	45	1	2	1618	155	2	1	2	2	1773	250790
34.18	W	84	20	2	2	0.50	45	1	2	1786	49	2	1	2	2	1835	87514
34.19	E	227	54	10	3	2.50	45	1	2	1544	224	2	2	2	2	1768	345856
34.19	W	227	54	17	9	4.25	45	1	2	1900	220	2	2	2	2	2120	418000
34.2	E	18	5	4	2	1.00	45	1	2	1359	73	2	1	2	2	1432	99207
34.21	E	42	11	1	0	0.25	35	1	2	885	38	2	1	2	2	923	33630
34.21	W	42	11	1	0	0.25	35	1	2	1947	129	2	1	2	2	2076	251163
34.22	E	30	8	11	4	2.75	35	0	2	1020	217	3	0	0	3	1237	221340
34.23	E	27	8	4	1	1.00	35	0	2	574	69	3	0	0	3	643	39606
34.24	W	21	4	6	1	1.50	35	0	2	1490	19	2	1	2	2	1509	28310
34.25	N	75	19	26	8	6.50	35	2	2	486	215	2	1	1	2	701	104490
34.26	N	37	9	0	0	0.00	35	1	1	253	41	2	1	2	2	294	10373
34.27	N	36	11	3	1	0.75	35	1	1	241	127	3	0	2	3	368	30607
34.27	S	36	11	0	0	0.00	35	1	1	303	49	3	0	2	3	352	14847
34.27	E	36	11	1	0	0.25	35	1	2	798	68	2	1	2	2	866	54264
34.27	W	36	11	4	1	1.00	35	1	2	1031	249	2	1	2	2	1280	256719
34.28	E	33	2	4	0	1.00	35	1	2	898	170	2	1	2	2	1068	152660
34.29	N	37	12	4	2	1.00	35	1	2	790	61	2	2	2	2	851	48190
34.29	S	37	12	4	2	1.00	35	1	2	375	146	2	2	2	2	521	54750
34.30	S	20	4	2	0	0.50	40	1	2	914	74	2	1	2	2	988	67636
34.31	N	58	15	2	1	0.50	40	1	2	1721	105	1	1	2	0	1826	180705
34.31	S	58	15	1	1	0.25	40	1	2	1205	110	1	1	2	0	1315	132550
34.31	E	58	15	1	0	0.25	35	1	1	233	106	2	1	2	2	339	24698
34.31	W	58	15	0	0	0.00	35	1	1	295	104	2	1	2	2	399	30680
34.32	N	57	15	0	0	0.00	45	1	2			1	1	2	0		
34.32	S	57	15	1	0	0.25	45	1	2			1	1	2	0		
34.32	E	57	15	0	0	0.00	35	1	1			2	1	2	2		
34.32	W	57	15	0	0	0.00	35	1	1			2	1	2	2		
34.33	N	18	4	3	0	0.75	35	1	2	1287	11	2	1	2	2	1298	14157

INT. NUM	DIR.	TOT ACC	TOT INJ	TOT LT	TOT LTI	AVG YR	S L	LT LANE	OPP LANE	PHT VOL	PHLT VOL	PHASING	LE OR LA	REG. SIG	SIG CON	LT + OPP	LT X OPP
34.34	S	37	12	2	1	0.50	35	1	2	1039	130	2	1	2	2	1169	135070
34.35	N	61	7	5	1	1.25	35	1	2	858	215	2	1	2	2	1073	184470
34.36	S	35	6	1	0	0.25	35	1	2	1190	118	2	1	2	2	1308	140420
34.37	N	52	11	6	2	1.50	35	1	1	602	373	3	0	2	3	975	224546
34.37	S	52	11	2	0	0.50	35	0	1	944	66	3	0	2	3	1010	62304
34.38	N	25	8	4	1	1.00	45	1	2	626	149	2	1	2	2	775	93274
34.39	E	45	12	11	2	2.75	35	1	2	565	103	2	1	2	2	668	58195
34.40	E	14	6	2	2	0.50	35	1	2	1507	156	2	1	2	2	1663	235092
34.41	E	46	11	6	2	1.50	35	1	2	1203	138	2	1	2	2	1341	166014
34.41	W	46	11	3	0	0.75	35	1	2	731	100	2	1	2	2	831	73100
34.42	E	42	16	8	4	2.00	45	1	2	903	294	2	1	2	2	1197	265482
34.42	W	42	16	6	2	1.50	45	1	2	1168	9	2	1	2	2	1177	10512
34.43	E	23	6	14	4	3.50	45	1	2	760	277	2	1	2	2	1037	210520
34.44	S	18	11	6	4	1.50	45	1	2	2619	34	2	1	2	1	2653	89046
34.45	N	81	17	1	1	0.25	45	1	2	1566	268	1	1	2	0	1834	419688
34.45	S	81	17	1	1	0.25	45	1	2	1207	143	1	1	2	0	1350	172601
34.45	E	81	17	1	0	0.25	45	1	1	346	75	2	1	2	2	421	25950
34.45	W	81	17	2	1	0.50	45	1	1	624	197	2	1	2	2	821	122928
34.46	N	60	10	8	2	2.00	45	1	2	633	56	2	1	2	2	689	35448
34.46	S	60	10	6	2	1.50	45	1	2	637	55	2	1	2	2	692	35035
34.47	N	43	14	6	2	1.50	35	1	2	1349	165	2	1	2	2	1514	222585
34.47	S	43	14	0	0	0.00	35	1	2	1085	89	2	1	2	2	1174	96565
34.48	N	20	6	3	0	0.75	35	1	2	1432	48	2	1	2	2	1480	68736
34.48	S	20	6	2	1	0.50	35	1	2	1192	13	2	1	2	2	1205	15496
34.49	N	25	3	1	0	0.25	35	1	1	157	151	3	0	2	3	308	23707
34.49	S	25	3	1	0	0.25	35	1	1	189	120	3	0	2	3	309	22680
34.50	E	20	4	0	0	0.00	45	1	1	728	25	2	1	2	2	753	18200
34.50	W	20	4	3	1	0.75	45	1	1	678	89	2	1	2	2	767	60342
34.51	N	21	5	4	2	1.00	45	1	1	336	20	2	1	2	2	356	6720
34.51	S	21	5	0	0	0.00	45	1	1	188	416	2	1	2	2	604	78208
34.52	S	16	4	3	1	0.75	35	1	2	746	177	2	1	1	2	923	132042
34.53	N	39	15	5	5	1.25	45	1	2	1558	231	2	1	2	2	1789	359898
34.53	S	39	15	2	1	0.50	45	1	2	530	456	2	1	2	2	986	241680
34.53	E	39	15	0	0	0.00	45	2	2	1289	421	1	1	2	0	1710	542669
34.53	W	39	15	0	0	0.00	45	2	2	1254	122	1	1	2	0	1376	152988
34.54	N	50	15	11	6	2.75	45	1	2	1731	163	2	1	2	2	1894	282153
34.54	S	50	15	6	1	1.50	45	1	2	683	182	2	1	2	2	865	124306
34.54	E	50	15	6	2	1.50	35	1	1	272	242	2	1	2	2	514	65824
34.54	W	50	15	5	2	1.25	35	1	1	446	98	2	1	2	2	544	43708
34.55	N	37	6	1	0	0.25	45	1	2	1147	61	1	1	2	0	1208	69967
34.55	S	37	6	0	0	0.00	45	1	2	776	278	1	1	2	0	1054	215728
34.55	E	37	6	2	1	0.50	35	1	1	460	138	2	1	2	2	598	63480
34.55	W	37	6	2	0	0.50	35	1	1	243	140	2	1	2	2	383	34020
34.56	S	29	4	6	2	1.50	45	1	2	1474	383	2	2	1	2	1857	564542
34.57	N	100	23	19	12	4.75	45	1	2	1783	338	2	2	1	2	2121	602654
34.57	S	100	23	11	8	2.75	45	1	2	1491	196	2	2	1	2	1687	292236
34.58	N	45	13	10	2	2.50	45	1	2	1519	171	2	1	2	2	1690	259749
34.58	S	45	13	6	4	1.50	45	1	2	1013	99	2	1	2	2	1112	100287
34.59	N	59	14	2	2	0.50	45	1	2	1327	239	1	1	2	0	1566	317153
34.59	S	59	14	3	3	0.75	45	1	2	1505	270	1	1	2	0	1775	406350
34.59	E	59	14	1	0	0.25	35	1	1	1261	120	2	1	2	2	1381	151320
34.59	W	59	14	1	0	0.25	35	1	1	547	24	2	1	2	2	571	13128
34.60	N	42	10	4	3	1.00	35	1	1	856	128	2	1	2	2	984	109568
34.60	S	42	10	4	3	1.00	35	1	1	671	32	2	2	2	2	703	21472
34.60	E	42	10	2	0	0.50	35	1	1	273	134	2	1	2	2	407	36582
34.60	W	42	10	0	0	0.00	35	1	1	465	125	2	2	2	2	590	58125
34.61	N	41	7	5	4	1.25	35	1	1	637	195	2	1	2	2	832	124215
34.62	N	51	14	1	0	0.25	35	1	1	414	138	2	1	2	2	552	57132
34.62	S	51	14	0	0	0.00	35	1	1	598	128	2	1	2	2	726	76544
34.63	E	48	12	1	0	0.25	35	0	2	628	49	3	0	2	3	677	30772
34.63	W	48	12	0	0	0.00	35	0	2	206	10	3	0	2	3	216	2060
34.64	N	15	5	2	1	0.50	40	1	2	1687	205	2	1	2	2	1892	345835

INT. NUM	DIR.	TOT ACC	TOT INJ	TOT LT	TOT LTI	AVG YR	S L	LT LANE	OPP LANE	PHT VOL	PHLT VOL	PHASING	LE OR LA	REG. SIG	SIG CON	LT + OPP	LT X OPP
34.65	S	3	1	0	0	0.00	55	1	2	1091	22	3	0	2	3	1113	24002
34.66	N			8	3	2.67	35	1	1	623	187	2	1	2	2	810	116501
34.66	S			0	0	0.00	35	1	1	506	52	2	1	2	2	558	26312
34.66	E			0	0	0.00	35	1	1	460	80	2	1	2	2	540	36800
34.66	W			5	3	1.67	35	1	1	598	235	2	1	2	2	833	140530
34.67	S			3	0	1.00	35	1	1	735	246	2	1	2	2	981	180810
34.68	N			1	0	0.33	35	1	1	1084	184	2	2	2	2	1268	199456
34.69	N			10	2	3.33	35	1	1	89	166	3	0	2	3	255	14774
34.69	S			1	0	0.33	35	1	1	233	39	3	0	2	3	272	9087
34.69	E			5	4	1.67	45	1	2	791	234	2	1	2	2	1025	185094
34.69	W			4	1	1.33	45	1	2	904	289	2	1	2	2	1193	261256
34.70	N			2	0	0.67	35	1	1	346	236	2	1	2	2	582	81656
34.70	S			2	0	0.67	35	1	1	217	206	2	1	2	2	423	44702
34.70	E			5	0	1.67	50	1	2	944	39	2	1	2	2	983	36816
34.70	W			1	0	0.33	50	1	2	951	49	2	1	2	2	1000	46599
34.71	N			2	0	0.67	45	1	2	1308	178	2	1	2	2	1486	232824
34.71	S			2	0	0.67	45	1	2	895	36	2	1	2	2	931	32220
34.71	E			2	0	0.67	35	1	1	37	152	3	0	2	3	189	5624
34.71	W			0	0	0.00	35	1	1	301	18	3	0	2	3	319	5418
34.72	N			0	0	0.00	35	1	1	299	66	2	1	2	2	365	19734
34.72	S			1	0	0.33	35	1	1	185	116	2	1	2	2	301	21460
34.72	E			6	4	2.00	45	1	2	716	125	2	1	2	2	841	89500
34.72	W			7	5	2.33	45	1	2	547	72	2	1	2	2	619	39384
34.73	N			21	10	7.00	45	1	2	1706	254	2	1	2	2	1960	433324
34.73	S			5	1	1.67	45	1	2	1015	100	2	1	2	2	1115	101500
34.73	E			8	2	2.67	35	1	1	247	661	2	1	2	2	908	163267
34.73	W			2	0	0.67	35	1	1	1220	119	2	1	2	2	1339	145180
34.74	N			0	0	0.00	35	1	1	248	175	2	1	2	2	423	43400
34.74	S			0	0	0.00	35	1	1	363	108	2	1	2	2	471	39204
34.74	E			1	0	0.33	45	1	2	1534	45	2	1	2	2	1579	69030
34.74	W			5	2	1.67	45	1	2	1047	245	2	1	2	2	1292	256515
34.75	E			4	1	1.33	45	1	2	1404	64	2	1	2	2	1468	89856
34.75	W			4	1	1.33	45	1	2	1238	230	2	1	2	2	1468	284740
34.76	N			2	2	0.67	35	1	1	608	243	2	1	2	2	851	147744
34.76	S			2	1	0.67	35	1	1	188	184	2	1	2	2	372	34592
34.76	E			9	7	3.00	45	1	2	969	430	2	1	2	2	1399	416670
34.76	W			5	2	1.67	45	1	2	1836	22	2	1	2	2	1858	40392
34.77	E			8	3	2.67	45	1	2	1197	177	2	1	2	2	1374	211869
34.78	W			39	12	13.00	45	1	2	1138	319	2	1	2	2	1457	363022
35.1	N	5	1	1	0	0.25	55	1	1	154	49	1	1	2	0	203	7546
35.1	S	5	1	0	0	0.00	55	1	1	119	29	1	1	2	0	148	3451
35.1	E	5	0	0	0	0.00	45	1	1	163	73	1	1	2	0	236	11899
35.1	W	5	0	0	0	0.00	45	1	1	205	47	1	1	2	0	252	9635
36.1	N	12	7	2	1	0.50	55	1	2	498	181	1	1	2	0	679	90138
36.2	N	15	4	0	0	0.00	55	1	2	531	170	1	1	2	0	701	90270
36.3	W	5	1	0	0	0.00	55	1	2	420	172	1	1	2	0	592	72240
37.1	N	37	10	0	0	0.00	55	1	2	1096	78	1	1	2	0	1174	85488
37.1	S	37	10	1	0	0.25	55	1	2	477	118	1	1	2	0	595	56286
37.2	E	14	4	1	1	0.25	55	1	2	1253	36	1	1	2	0	1289	45108
37.3	N	26	9	0	0	0.00	55	1	1			1	1	2	0		
37.3	S	26	9	0	0	0.00	55	1	1			1	1	2	0		
37.3	E	26	9	4	3	1.00	55	2	2	555	339	1	1	2	0	894	188145
37.3	W	26	9	0	0	0.00	55	1	2	466	13	1	1	2	0	479	6058
37.4	N	20	9	2	2	0.50	55	1	2	807	22	3	0	2	3	829	17754
37.4	S	20	9	1	1	0.25	55	1	2	924	22	3	0	2	3	946	20328
37.5	W	5	0	1	0	0.25	55	0	1	867	9	3	0	2	3	876	7803
37.6	E	23	9	1	0	0.25	55	1	2			1	1	2	0		
37.7	E	11	3	2	1	0.50	45	1	2	1253	36	1	1	2	0	1289	45108
42.1	N	17	6	1	1	0.25	55	1	2			1	1	2	0		
42.1	S	17	6	1	0	0.25	55	1	2	344	21	[illegible]	1	2	0	365	7224
45.1	N	14	3	0	0	0.00	55	1	2	852	131	1	1	2	0	[illegible]	[illegible]
45.2	N	31	11	2	1	0.50	[illegible]	1	2	[illegible]	[illegible]	[illegible]	1	2	0	[illegible]	[illegible]

INT. NUM	DIR.	TOT ACC	TOT INJ	TOT LT	TOT LTI	AVG YR	S L	LT LANE	OPP LANE	PHT VOL	PHLT VOL	PHASING	LE OR LA	REG. SIG	SIG CON	LT + OPP	LT X OPP
45.2	S	31	11	1	0	0.25	55	1	2			1	1	2	0		
45.3	S	19	6	0	0	0.00	55	1	2			1	1	2	0		
45.4	N	10	2	0	0	0.00	55	1	2	366	135	1	1	2	0	501	49410
45.4	S	10	2	1	0	0.25	55	1	2	262	29	1	1	2	0	291	7598
45.5	S	31	16	7	5	1.75	55	0	2			3	0	2	3		
45.6	N	13	8	1	1	0.25	45	1	2	238	43	3	0	2	3	281	10234
45.6	S	13	8	1	0	0.25	45	1	2	267	21	3	0	2	3	288	5607
46.1	E	2	2	1	0	0.25	45	1	1	617	21	3	0	2	3	638	12957
46.1	W	2	2	0	0	0.00	45	1	1	261	39	3	0	2	3	300	10179
47.1	N	12	2	0	0	0.00	55	0	2	938	12	3	0	2	3	950	11256
47.1	S	12	2	0	0	0.00	55	0	2	1269	61	3	0	2	3	1330	77409
47.2	N	9	2	0	0	0.00	55	1	1	308	38	1	1	2	0	346	11704
47.2	S	9	2	0	0	0.00	55	1	1	142	45	1	1	2	0	187	6390
47.2	E	9	2	0	0	0.00	55	1	2	150	137	1	1	2	0	287	20550
47.2	W	9	2	0	0	0.00	55	1	2	237	11	1	1	2	0	248	2607
47.3	N	29	4	1	1	0.25	55	1	2	1508	27	1	1	2	0	1535	40716
47.3	S	29	4	0	0	0.00	55	1	2	544	142	1	1	2	0	686	77248
47.4	S	14	6	2	2	0.50	55	2	2			1	1	2	0		
47.5	N	17	9	0	0	0.00	55	1	2	934	56	1	1	2	0	990	52304
47.5	S	17	9	0	0	0.00	55	1	2	598	78	1	1	2	0	676	46644
47.6	N	21	2	0	0	0.00	35	1	2			1	1	2	0		
47.6	S	21	2	1	0	0.25	35	1	2			1	1	2	0		
47.7	N	22	5	2	1	0.50	45	1	2	1402	83	1	1	2	0	1485	116366
47.8	N	17	5	2	0	0.50	45	1	2	1457	191	1	1	2	0	1648	278287
47.9	N	28	2	1	0	0.25	45	1	2			1	1	2	0		
47.9	S	28	2	0	0	0.00	45	1	2			1	1	2	0		
47.9	E	28	2	2	0	0.50	45	1	1			1	1	2	0		
47.9	W	28	2	0	0	0.00	45	1	1			1	1	2	0		
47.10	N	12	3	0	0	0.00	45	1	2			1	1	2	0		
47.10	S	12	3	0	0	0.00	45	1	2			1	1	2	0		
47.11	E	14	0	1	0	0.25	45	1	2	235	63	1	1	2	0	298	14805
47.12	E	13	2	0	0	0.00	45	1	2			1	1	2	0		
47.12	W	13	2	0	0	0.00	45	1	2			1	1	2	0		
48.1	N	3	0	0	0	0.00	55	1	2			1	1	2	0		
49.1	N	13	4	2	1	0.50	45	0	1			2	1	2	2		
49.1	S	13	4	0	0	0.00	45	1	1			2	1	2	2		
51.1	N	12	3	0	0	0.00	55	1	1			3	0	2	3		
51.1	S	12	3	0	0	0.00	55	1	1			3	0	2	3		
51.1	E	12	3	3	1	0.75	55	1	1			3	0	2	3		
51.1	W	12	3	0	0	0.00	55	1	1			3	0	2	3		
51.2	N	76	32	9	2	2.25	35	0	2	742	22	2	1	1	2	764	16324
51.2	S	76	32	6	4	1.50	35	1	2	987	110	2	1	1	2	1097	108570
51.2	E	76	32	3	1	0.75	35	1	2	386	70	3	0	2	3	456	27020
51.2	W	76	32	9	2	2.25	35	0	1	299	133	3	0	2	3	432	39767
51.3	N	37	10	1	0	0.25	35	1	2	901	83	2	1	1	2	984	74783
51.3	S	37	10	1	0	0.25	35	1	2	805	28	2	1	1	2	833	22540
51.3	E	37	10	1	0	0.25	35	0	1	111	80	3	0	1	3	191	8880
51.3	W	37	10	0	0	0.00	35	0	1	144	50	3	0	1	3	194	7200
51.4	N	69	22	1	0	0.25	45	1	2	1016	33	1	1	2	0	1049	33528
51.4	S	69	22	1	0	0.25	45	1	2	917	119	1	1	2	0	1036	109123
51.5	N	13	5	0	0	0.00	45	1	2			1	1	2	0		
51.5	S	13	5	0	0	0.00	45	1	2			1	1	2	0		
51.6	N	6	2	0	0	0.00	55	1	1	57	125	3	0	2	3	182	7125
51.6	S	6	2	1	1	0.25	55	1	1	228	116	3	0	2	3	344	26448
51.6	E	6	2	0	0	0.00	55	1	1	403	22	3	0	2	3	425	8866
51.6	W	6	2	0	1	0.00	55	1	1	292	97	3	0	2	3	389	28324
54.1	E	24	5	16	5	4.00	35	1	2			2	1	1	2		
54.2	S	11	3	4	2	1.00	45	1	2	530	195	2	1	1	2	725	103350
54.3	E	12	5	1	0	0.25	45	1	1			3	0	2	3		
56.1	N	44	14	11	6	2.75	35	1	1			3	0	1	3		
56.1	S	44	14	0	0	0.00	35	1	1			3	0	2	3		
56.1	E	44	14	0	0	0.00	45	1	1			2	1	2	2		

INT. NUM	DIR.	TOT ACC	TOT INJ	TOT LT	TOT LTI	AVG YR	S L	LT LANE	OPP LANE	PHT VOL	PHLT VOL	PHASING	LE OR LA	REG. SIG	SIG CON	LT + OPP	LT X OPP
56.1	W	44	14	6	3	1.50	45	1	1			2	1	2	2		
56.2	N	61	22	13	4	3.25	35	0	2			2	1	2	2		
56.2	S	61	22	15	7	3.75	35	0	2			2	1	2	2		
56.3	E	16	5	3	1	0.75	45	1	3	1407	102	2	1	1	2	1509	143514
56.3	W	16	5	0	0	0.00	45	1	2			2	1	2	2		
56.4	E	31	7	6	2	1.50	45	1	3	1094	522	2	1	2	2	1616	571068
56.5	E	69	19	8	2	2.00	35	0	2			2	1	1	2		
56.5	W	69	19	4	4	1.00	35	0	2			2	1	1	2		
56.6	S	34	4	1	0	0.25	45	1	2			1	1	2	0		
56.7	E	24	5	1	0	0.25	45	1	2			1	1	2	0		
56.7	W	24	5	1	0	0.25	45	1	2			1	1	2	0		
56.8	E	9	4	4	2	1.00	45	1	2			3	0	2	3		
56.9	N	75	18	5	2	1.25	45	1	2			2	1	1	2		
56.9	S	75	18	6	3	1.50	45	1	2			2	1	1	2		
57.1	S	25	3	0	0	0.00	55	1	2	748	23	3	0	2	3	771	17204
57.2	N	11	5	1	0	0.25	55	1	2	610	8	3	0	2	3	618	4880
57.2	S	11	5	1	0	0.25	55	1	2	292	66	3	0	2	3	358	19272
57.3	N	34	10	1	0	0.25	55	1	2			1	1	2	0		
57.3	S	34	10	1	0	0.25	55	1	2			1	1	2	0		
57.4	N	24	6	2	1	0.50	55	1	2	1472	65	3	0	2	3	1537	95680
57.4	S	24	6	3	2	0.75	55	1	2	949	145	3	0	2	3	1094	137605
57.5	S	7	0	2	2	0.50	55	1	2	445	257	1	1	2	0	702	114365
57.6	N	17	7	0	0	0.00	55	1	2	354	101	1	1	2	0	455	35754
57.6	S	17	7	0	0	0.00	55	1	2	639	113	1	1	2	0	752	72207
57.7	S	15	4	2	1	0.50	55	1	2	1191	77	3	0	2	3	1268	91707
59.1	N	34	10	5	1	1.25	55	1	2	1140	37	3	0	2	3	1177	42180
59.2	N	65	14	6	2	1.50	35	1	1			2	1	2	2		
59.2	S	65	14	8	3	2.00	35	0	1			2	1	2	2		
59.3	N	24	9	2	2	0.50	35	1	2	772	83	1	2	2	0	855	64076
59.4	N	51	16	8	4	2.00	35	1	1			2	1	1	2		
59.4	S	51	16	20	8	5.00	35	1	1			2	1	1	2		
62.1	N	6	2	2	1	0.50	55	1	2			3	0	2	3		
62.1	S	6	2	1	0	0.25	55	1	2			3	0	2	3		
62.2	W	9	4	4	0	1.00	55	1	2	73	80	3	0	1	3	153	5840
62.2	E	9	4	0	0	0.00	55	1	1	94	23	3	0	1	3	117	2162
62.2	N	9	4	0	0	0.00	55	1	1	275	107	3	0	2	3	382	29425
62.2	S	9	4	0	0	0.00	55	1	1	191	27	3	0	2	3	218	5157
63.1	N	13	3	1	0	0.25	55	1	2	103	14	3	0	2	3	117	1442
63.1	S	13	3	0	0	0.00	55	1	2	189	98	3	0	2	3	287	18522
63.1	E	13	3	1	0	0.25	55	1	2	544	101	3	0	2	3	645	54944
63.1	W	13	3	1	0	0.25	55	1	2	306	77	3	0	2	3	383	23562
63.2	E	11	3	0	0	0.00	55	1	2	500	64	1	1	2	0	564	32000
63.2	W	11	3	0	0	0.00	55	1	2	674	81	1	1	2	0	755	54594
63.3	E	18	6	1	0	0.25	55	1	2	872	107	1	1	2	0	979	93304
63.3	W	18	6	2	0	0.50	55	1	2	958	199	1	1	2	0	1157	190642
63.4	E	6	0	0	0	0.00	55	1	2	349	51	1	1	2	0	400	17799
63.4	W	6	0	1	0	0.25	55	1	2	437	84	1	1	2	0	521	36708
63.5	E	6	4	1	0	0.25	55	1	1	251	140	3	0	2	3	391	35140
63.5	W	6	4	0	0	0.00	55	1	1	236	17	3	0	2	3	253	4012
63.6	E	11	4	0	0	0.00	55	1	2			1	1	2	0		
63.6	W	11	4	1	0	0.25	55	1	2			1	1	2	0		
64.1	E	5	2	0	0	0.00	55	1	1	279	24	1	1	2	0	303	6696
64.1	W	5	2	1	0	0.25	55	1	1	279	154	1	1	2	0	433	42966
73.1	E	15	2	0	0	0.00	55	0	1	395	139	3	0	2	3	534	54905
73.2	E	19	8	0	0	0.00	55	1	2			1	1	2	0		
73.3	E	71	30	3	2	0.75	45	1	2			3	0	2	3		
73.3	W	71	30	9	3	2.25	45	1	2			3	0	2	3		
73.4	E	120	39	14	7	3.50	45	0	2			3	0	2	3		
73.4	W	120	39	12	6	3.00	45	0	2			3	0	2	3		
73.5	W	53	14	5	2	1.25	45	0	1	965	78	3	0	2	3	1043	75270
74.1	N	19	5	0	0	0.00	45	1	2			1	1	2	0		
74.1	S	19	5	1	0	0.25	45	1	2			1	1	2	0		

INT. NUM	DIR.	TOT ACC	TOT INJ	TOT LT	TOT LTI	AVG YR	S L	LT LANE	OPP LANE	PHT VOL	PHLT VOL	PHASING	LE OR LA	REG. SIG	SIG CON	LT + OPP	LT X OPP
76.1	W	99	25	4	1	1.00	45	1	1	366	108	1	1	2	0	474	39528
76.2	W	66	16	17	9	4.25	45	1	2			3	0	2	3		
77.1	W	5	1	0	0	0.00	45	1	1	214	35	3	0	1	3	249	7490
79.1	N	19	7	0	0	0.00	55	0	1	250	40	3	0	2	3	290	10000
79.1	S	19	7	3	0	0.75	55	0	1	90	7	3	0	2	3	97	630
79.1	E	19	7	0	0	0.00	55	1	1	211	114	1	1	2	0	325	24054
79.1	W	19	7	0	0	0.00	55	1	1	216	68	1	1	2	0	284	14688
79.2	N	24	10	0	0	0.00	55	1	2	194	30	1	1	2	0	224	5820
79.2	S	24	10	2	2	0.50	55	1	2	245	51	1	1	2	0	296	12495
79.2	E	24	10	0	0	0.00	55	0	1	71	10	3	0	1	3	81	710
79.2	W	24	10	4	0	1.00	55	0	1	53	37	3	0	1	3	90	1961
79.3	N	9	1	0	0	0.00	55	1	2	123	106	3	0	2	3	229	13038
79.3	S	9	1	3	1	0.75	55	1	1	112	169	3	0	2	3	281	18928
79.3	E	9	1	2	1	0.50	55	1	2	434	42	3	0	2	3	476	18228
79.3	W	9	1	1	1	0.25	55	1	2	229	28	3	0	2	3	257	6412
79.4	E	27	11	1	1	0.25	45	1	2	311	34	1	1	2	0	345	10574
81.1	E	16	6	0	0	0.00	55	1	2			1	1	2	0		
81.1	W	16	6	3	1	0.75	55	1	2			1	1	2	0		
81.2	N	35	10	0	0	0.00	55	1	2	133	31	3	0	2	3	164	4123
81.2	S	35	10	0	0	0.00	55	1	2	72	300	3	0	2	3	372	21600
81.2	E	35	10	0	0	0.00	45	1	2	582	59	2	1	1	1	641	34338
81.2	W	35	10	1	0	0.25	45	1	2	722	47	2	1	1	1	769	33934
82.1	N	3	0	0	0	0.00	55	1	2	699	225	1	1	2	0	924	157275
82.2	N	24	10	7	4	1.75	55	1	2			3	0	2	3		
87.1	E	26	9	1	1	0.25	55	1	2			1	1	2	0		
87.1	W	26	9	3	2	0.75	55	1	2			1	1	2	0		
88.1	E	11	3	0	0	0.00	45	1	1	222	21	3	0	1	3	243	4662
88.1	W	11	3	2	0	0.50	45	1	1	233	203	3	0	1	3	436	47299
88.2	E	9	2	0	0	0.00	45	1	1	416	104	3	0	1	3	520	43264
88.2	W	9	2	1	0	0.25	45	1	1	367	68	3	0	1	3	435	24956
89.1	E	11	3	2	0	0.50	45	1	1	125	61	3	0	2	3	186	7625
89.1	W	11	3	1	0	0.25	45	1	1	105	59	3	0	2	3	164	6195
89.2	N	25	10	2	0	0.50	55	1	1	90	32	3	0	2	3	122	2880
89.2	S	25	10	3	3	0.75	55	1	1	90	34	3	0	2	3	124	3060
89.2	E	25	10	1	0	0.25	45	0	1	171	14	3	0	2	3	185	2394
89.2	W	25	10	0	0	0.00	45	0	1	201	17	3	0	2	3	218	3417
89.3	N	16	7	0	0	0.00	55	1	2	159	37	3	0	2	3	196	5883
89.3	S	16	7	0	0	0.00	55	1	2	131	39	3	0	2	3	170	5109
89.3	E	16	7	1	1	0.25	35	0	1	180	54	3	0	2	3	234	9720
89.3	W	16	7	0	0	0.00	35	0	1	163	29	3	0	2	3	192	4727
89.4	N	12	3	1	1	0.25	55	1	2	174	18	1	1	2	0	192	3132
89.4	S	12	3	1	1	0.25	55	1	2	192	136	1	1	2	0	328	26112
97.1	S	42	23	6	3	1.50	55	0	2	684	37	3	0	2	3	721	25308
97.2	N	24	10	0	0	0.00	55	1	1	368	252	1	1	2	0	620	92736
97.3	N	9	2	0	0	0.00	55	1	2	242	52	1	1	2	0	294	12584
97.4	S	12	1	1	0	0.25	55	0	2	572	74	3	0	1	3	646	42328
98.1	S	27	12	3	2	0.75	55	1	2			1	1	2	0		
98.2	S	19	9	1	0	0.25	55	1	2	1053	52	1	1	2	0	1105	54756
98.3	N	14	5	1	0	0.25	45	1	1			1	1	2	0		
98.3	S	14	5	0	0	0.00	45	1	2			1	1	2	0		
98.4	S	4	2	1	1	0.25	55	1	2			1	1	2	0		
100.1	N	53	21	1	0	0.25	45	1	2	1030	70	1	1	2	0	1100	72100
100.2	N	25	9	5	1	1.25	45	1	2	1120	180	1	1	2	0	1300	201600
100.3	S	21	4	1	0	0.25	45	1	2	1120	50	1	1	2	0	1170	56000
100.4	N	17	7	0	0	0.00	45	1	2			1	1	2	0		
100.4	S	17	7	0	0	0.00	45	1	2			1	1	2	0		
100.5	S	21	6	2	1	0.50	45	1	2	446	15	1	1	2	0	461	6690
103.1	E	13	6	0	0	0.00	55	0	1	190	50	3	0	2	3	240	9500
103.1	W	13	6	0	0	0.00	55	0	1	524	16	3	0	2	3	540	8384
105.1	S	18	6	1	0	0.25	45	1	1			1	1	2	0		
107.1	N	14	5	1	1	0.25	35	1	1			1	1	2	0		
107.1	S	14	5	0	0	0.00	35	1	1			1	1	2	0		

INT. NUM	DIR.	TOT ACC	TOT INJ	TOT LT	TOT LTI	AVG YR	S L	LT LANE	OPP LANE	PHT VOL	PHLT VOL	PHASING	LE OR LA	REG. SIG	SIG CON	LT + OPP	LT X OPP
109.1	N	20	9	1	0	0.25	55	0	1	107	63	3	0	2	3	170	6741
109.1	S	20	9	2	2	0.50	55	0	1	175	93	3	0	2	3	268	16275
109.1	E	20	9	2	0	0.50	55	0	1	79	30	3	0	2	3	109	2370
109.1	W	20	9	1	0	0.25	55	0	1	29	116	3	0	2	3	145	3364
109.2	N	19	4	0	0	0.00	55	1	1	59	38	1	1	2	0	97	2242
109.2	S	19	4	0	0	0.00	55	1	1	141	62	1	1	2	0	203	8742
109.2	E	19	4	0	0	0.00	35	1	2	240	29	1	1	2	0	269	6960
109.2	W	19	4	2	0	0.50	35	1	2	205	82	1	1	2	0	287	16810
114.1	N	38	14	1	1	0.25	55	1	2			1	1	2	0		
114.1	S	38	14	2	2	0.50	55	1	2			1	1	2	0		
114.2	E	11	4	3	1	0.75	55	1	2			1	1	2	0		
114.2	W	11	4	2	1	0.50	55	1	2			1	1	2	0		
115.1	N	23	6	3	2	0.75	55	1	1	50	35	3	0	2	3	85	1750
115.1	S	23	6	1	0	0.25	55	1	1	44	17	3	0	2	3	61	748
115.1	E	23	6	4	0	1.00	55	1	1	300	20	3	0	2	3	320	6000
115.1	W	23	6	0	0	0.00	55	1	1	252	28	3	0	2	3	280	7056
116.1	E	6	3	0	0	0.00	55	1	1	165	29	1	1	2	0	194	4785
116.1	W	6	3	2	2	0.50	55	1	1	173	145	1	1	2	0	318	25085
120.1	E	20	4	0	0	0.00	55	1	2	684	113	1	1	2	0	797	77292
120.2	W	5	4	1	0	0.25	55	1	2	1268	69	3	0	2	3	1337	87492
120.3	W	27	5	1	1	0.25	55	1	2	1160	150	1	1	2	0	1310	174000
120.4	E	36	11	10	3	2.50	45	0	1	609	441	2	1	2	2	1050	268569

APPENDIX C

LEFT-TURN DELAY RESULTS

The statistical approach used to evaluate left-turn delays obtained from TRAF-NETSIM simulations involved regression lines. A series of lines were tested to determine the best fit through the available data. Regression lines fitted through the data were mostly exponential (with or without a constant) and in some cases the use of polynomial equations was utilized. For all regression models, high multiple determination coefficients (r-square) were observed indicating acceptable fit of the data.

The first set of analysis dealt with the average stopped delay of the left turn. The results of these analyses show similar patterns for the delay for intersections with one and two lane approaches (opposing lanes) (Figures C1 and C2, respectively). For both one- and two-lane approaches, significant differences were noted in the level of delay between protected-only and permissive left-turn phasing. While left-turn delays would generally be expected to be less than 30 seconds per vehicle for permissive phasing, delays in excess of 70 seconds per vehicle were observed for protected-only phasing. Therefore, the use of permitted phasing, either permissive or P/P, will reduce left-turn delays significantly. Permissive phasing can reduce left-turn delays by more than 50 percent for large opposing volumes and even higher reductions (in excess of 80 percent) can be achieved for small opposing volumes.

When comparing permissive and P/P phasing, the use of permissive phasing will produce, in general, even smaller delays. This trend is more apparent for the two-lane approaches, while no significant differences were found between the two phasing schemes for one lane approaches. Also, for opposing volumes less than 1,000 vehicles per hour (vph), no significant reductions were noted between the two phasing schemes for the two-lane approaches. For opposing volumes larger than 1,000 vph, the permissive phasing produces longer left-turn delays.

Considering only the delays of left-turn traffic, the following can be concluded: protected-only phasing will cause high left-turn delays while permissive phasing can reduce those delays; for one opposing lane, the use of permissive or P/P phasing will produce similar left-turn delays; for two opposing lanes, P/P phasing will produce lower delays than permissive; and the desired left-turn phasing for both one and two-lane approaches is P/P since it produces similar or smaller delays than permissive phasing and provides some level of safety for left-turning vehicles.

The next set of analyses considered the combined effect of both the opposing volume and left-turn volume by using their product. The data from these analyses are shown in Figures C3 and C4 for one- and two-lane approaches, respectively. These figures indicate that, for any volume product, the phase scheme that minimizes left-turn delays is permissive. Higher delays are shown for P/P phasing with even higher levels of delay for protected-only phasing. Each line shown in these figures can be considered as the dividing line between the desirable (or acceptable) left turn delay and the phase scheme that would produce such delays. The area between the x-axis and the first line indicates the combination of delay and volume product for which the preferred scheme is permissive; the area between the two lines indicates the combinations of delay and volume product for which the P/P phase scheme is preferred; and the area above the second line represents the combinations where protected-only is preferred. These figures can be used, based on the acceptable left-turn delay and the volume product (left-turn volume times opposing volume), to make decisions regarding the appropriate left turn phase to select.

The data in Figures C3 and C4 can be utilized in two ways. They can be used to either determine the preferred phasing plan given a volume product and acceptable left-turn delay or to estimate the left-turn delay under each phasing plan given a specific volume product. The use of these figures and their two different utilizations is illustrated in the following example. Assume a one-lane approach with a left-turn volume of 100 vph and an opposing volume of 500 vph and thus a volume product of 50,000. If the acceptable left-turn delay is 35 seconds per vehicle, the phasing plan that can achieve this delay is the P/P, since the intersection of the vertical projection of the 50,000 product and the horizontal projection of the 35 seconds per vehicle lies in the area of the P/P phase (utilization 1). However, permissive phasing can be used if desired delays need to be less than 12 seconds per vehicle, P/P should be used if acceptable delays are in the range of 12 to 66 seconds per vehicle, and protected-only phasing can be used if acceptable delays are larger than 66 seconds per vehicle (utilization 2). These limits were determined by the vertical projection of the 50,000 product and its intersection with the boundary lines.

A third analysis involves the determination of the left-turn phase scheme based on the left-turn volume and its opposing volume. Two different methods were developed for study of this alternative. The first method used an average left-turn stopped delay of 15 seconds per vehicle while the second method used a left-turn delay of 30 seconds per vehicle. For each method, left-turn delays were grouped in two categories based on the delay used (delays larger or shorter than 15 or 30 seconds per vehicle). The results for the 15 seconds per vehicle alternative are shown in Figures C5 and C6 for one and two-lane approaches, respectively. Left-turn and opposing volume combinations for delays of 30 seconds per vehicle were obtained only for two lane approaches (Figure C7) because all delays for one-lane approaches were less than 30 seconds for both permissive and P/P phasing. The area below the line drawn in all three figures indicates the combinations of volumes where the preferred phasing scheme is permissive while the area above the line shows the combinations where the P/P phase can be used. This line indicates the limits of the volume combinations and phasing schemes where the 15 or 30 seconds per vehicle average stopped delay can be maintained. As in the previous analysis, as the opposing volume increase, the left-turn volume that can be accommodated with a permissive phase decreases which indicates the reduction of available gaps to complete a left turn.

The information given in Figures C5 through C7 can be utilized in two manners. They can be used to determine the phasing scheme that will produce a 15 or 30 second per vehicle delay for a given combination of left- turn and opposing volumes or they can determine the maximum left turn volume that can be accommodated for a given phasing scheme and opposing volume fro 15 or 30 seconds of delay per vehicle. The use of these figures and their different utilizations is illustrated in the following example. Assume a two-lane approach with a left-turn volume of 150 vph and an opposing volume of 1,000 vph. If an average left-turn delay of 15 seconds per vehicle is to be maintained, P/P phasing must be used. This conclusion was drawn from Figure C6 since the intersection of the vertical projection of the 1,000 vph opposing volume and the horizontal projection of the 150 vph left-turning volume lies above the line indicating P/P phasing. Also, to maintain an average 15 second per vehicle stopped delay for an opposing volume of 1,000 vph, the maximum left-turn volume can be 120 for permissive phasing (utilization 2). If the left-turn volume becomes larger, P/P phasing is needed to maintain the 15 seconds per vehicle delay.

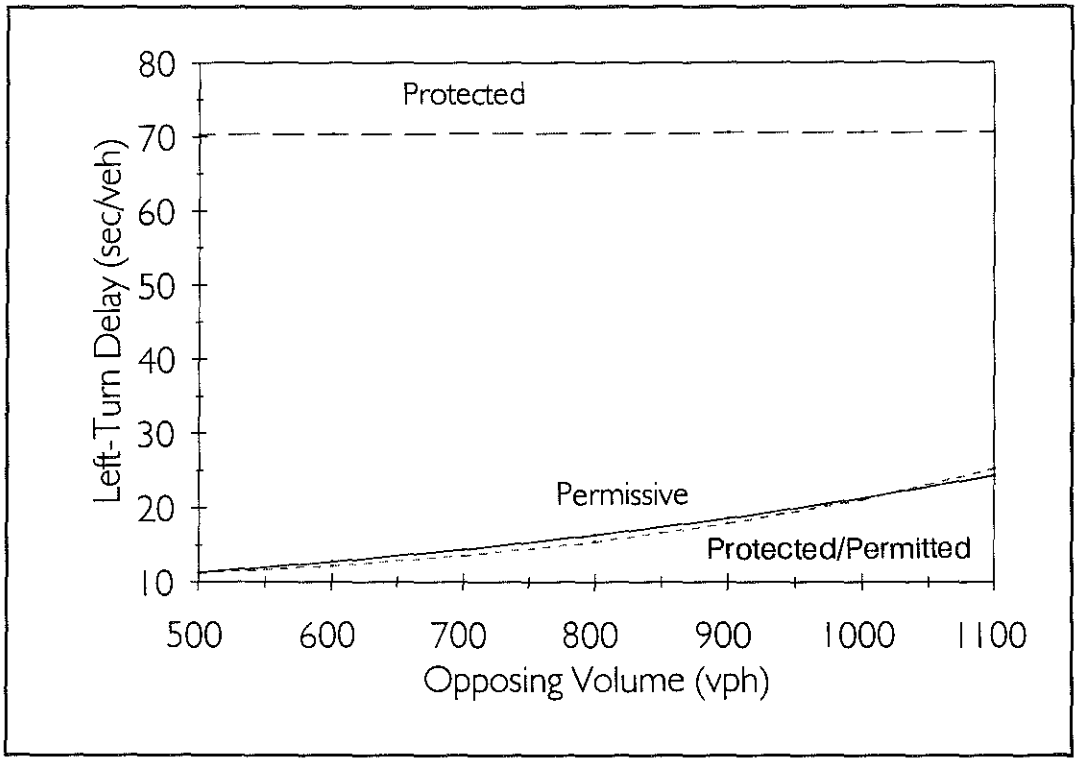


Figure C1. Left-Turn Delays vs. Opposing Volume, 1-Lane Approaches

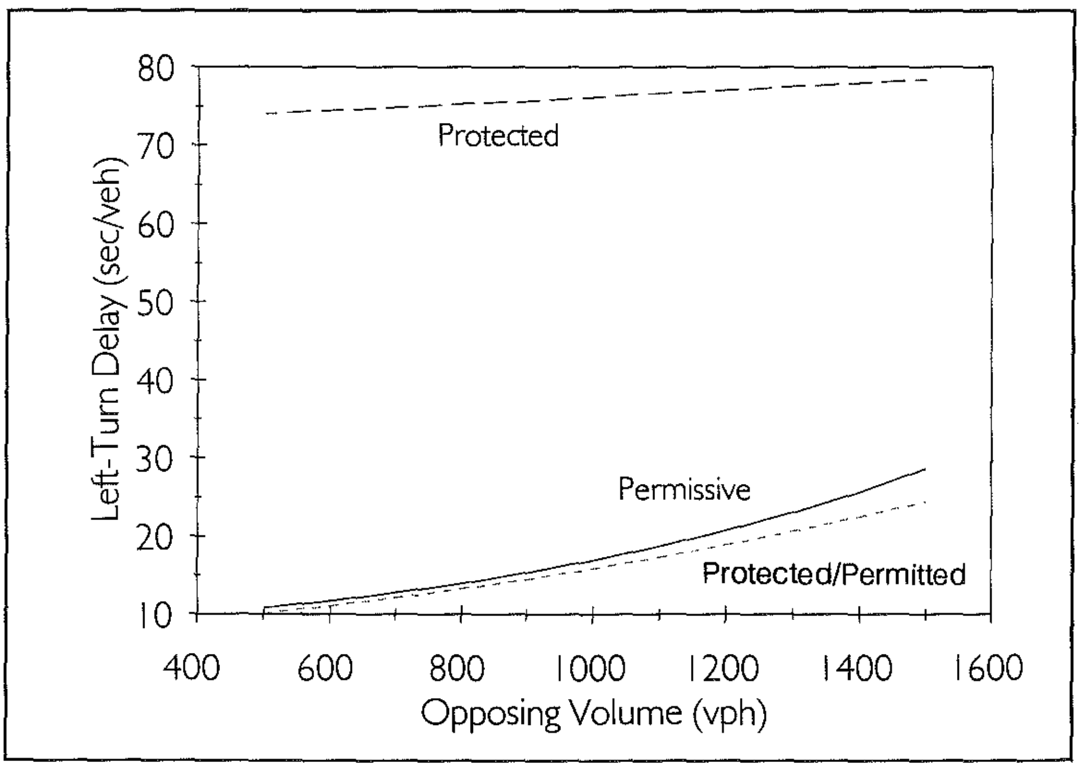


Figure C2. Left-Turn Delays vs Opposing Volume, 2-Lane Approaches

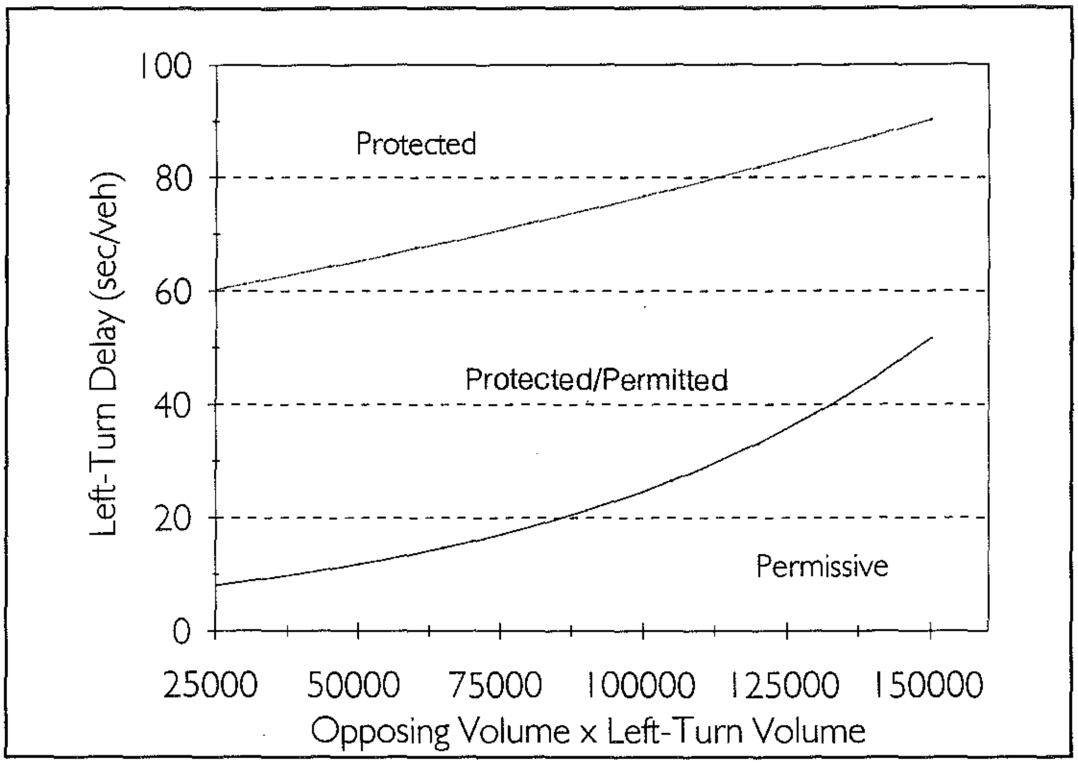


Figure C3. Volume Product vs. Left-Turn Delays, 1-Lane Approaches

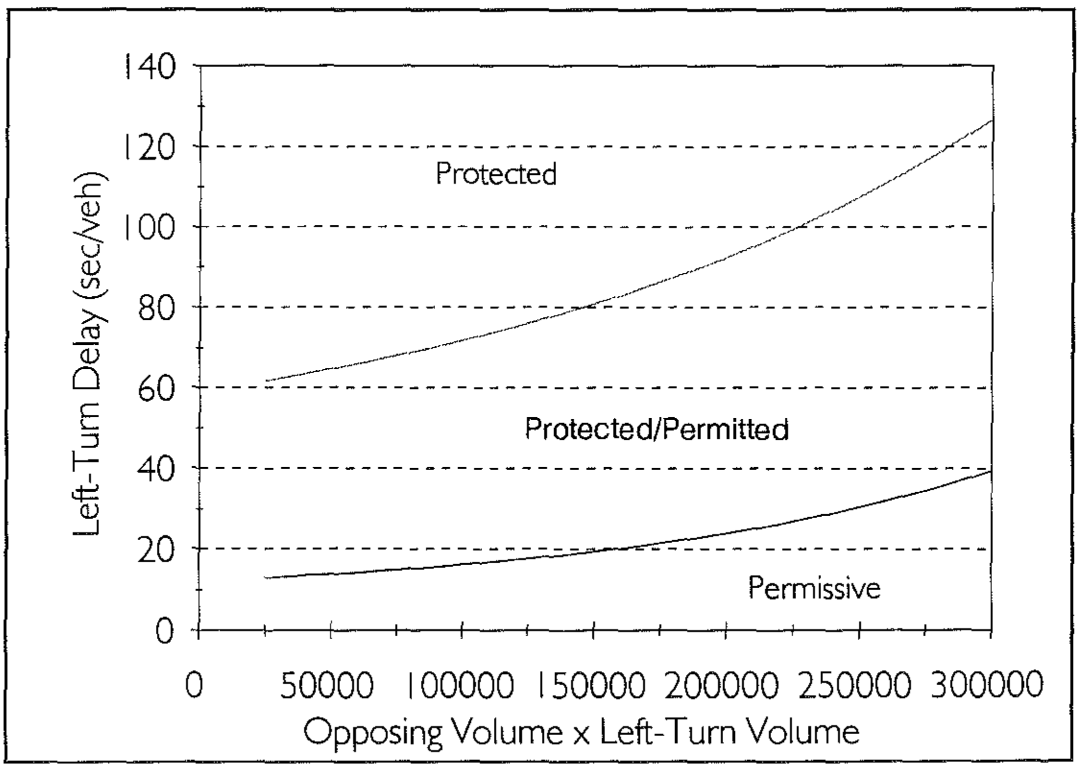


Figure C4. Volume Product vs. Left-Turn Delays, 2-Lane Approaches

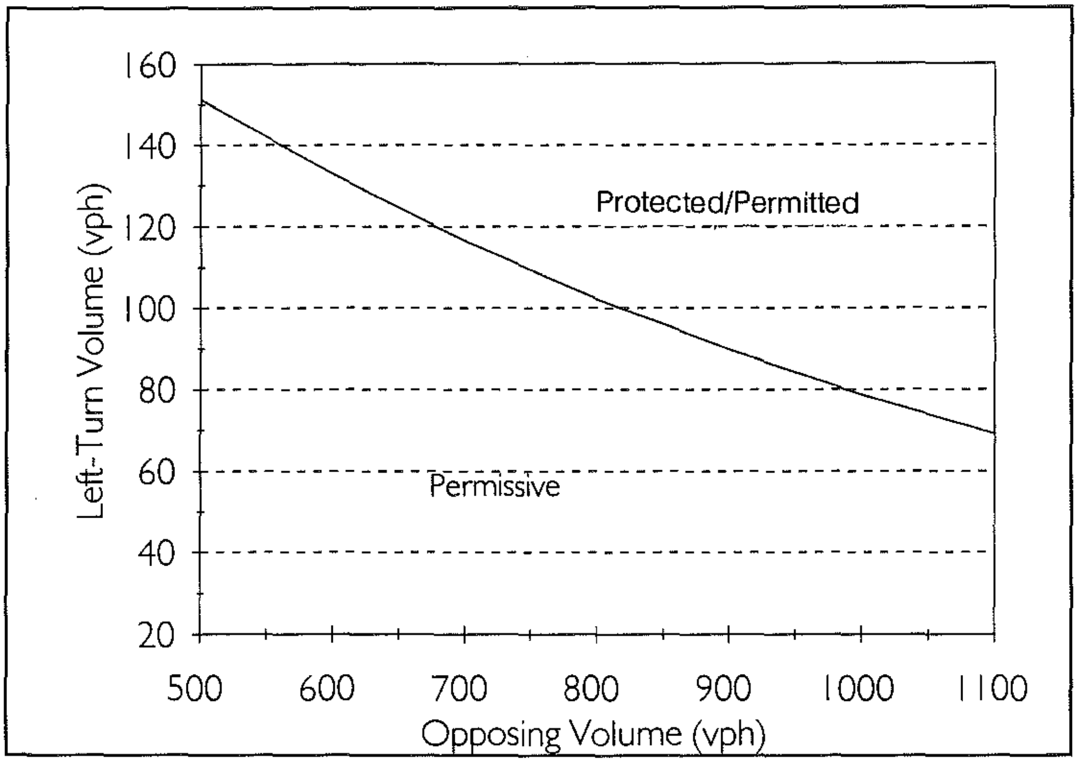


Figure C5. Fifteen Second Equivalent Delay for Left-Turns, 1-Lane Approaches

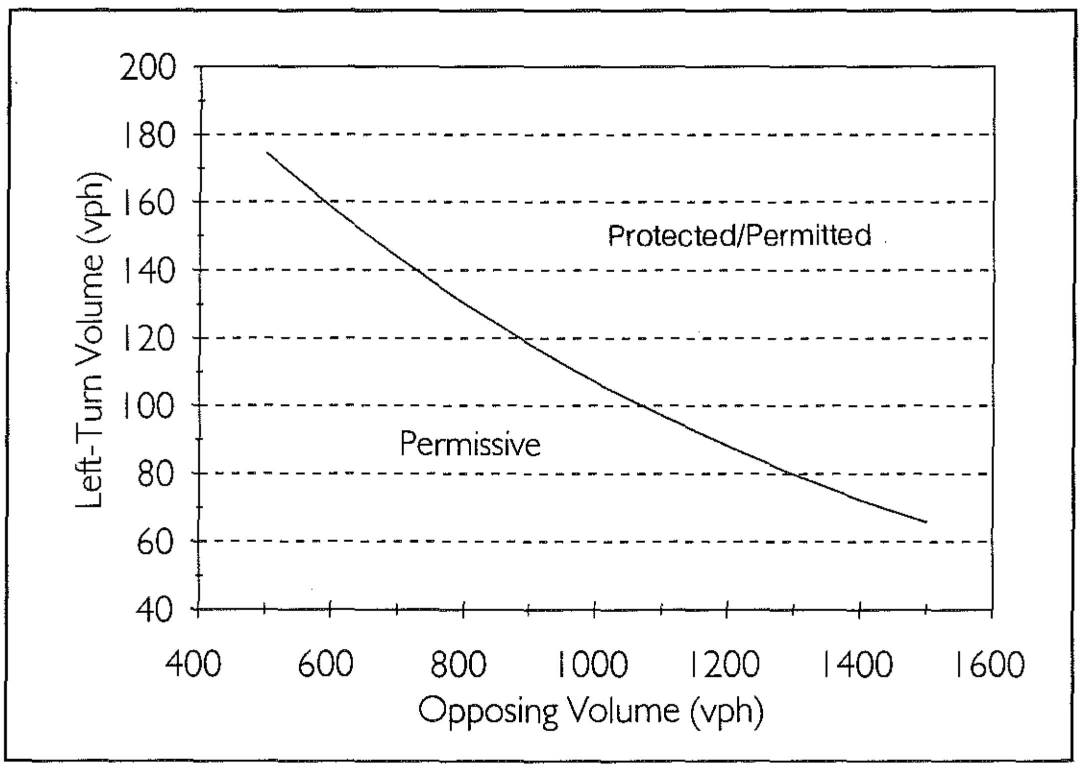


Figure C6. Fifteen Second Equivalent Delay for Left-Turns, 2-Lane Approaches

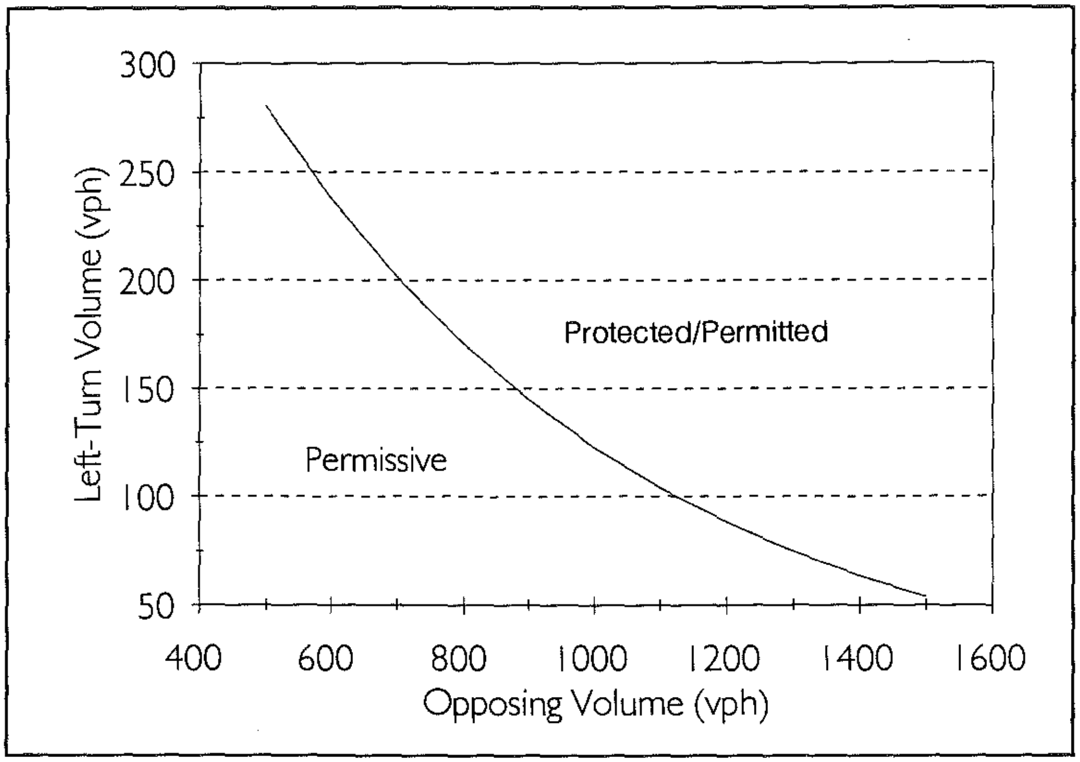


Figure C7. Thirty Second Equivalent Delay for Left-Turns, 2-Lane Approaches