# IMPACTS ON SAFETY OF LEFT-TURN TREATMENT AT HIGH SPEED SIGNALIZED INTERSECTIONS

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Iowa Highway Research Board
Project HR - 347

January 1994

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## Abstract

Left-turning traffic is a major source of conflicts at intersections. Though an average of only 10 percent to 15 percent of all approach traffic turns left, these vehicles are involved in approximately 45 percent of all accidents.

This report presents the results of research conducted to develop models which estimate approach accident rates at high speed signalized intersections. The objective of the research was to quantify the relationship between traffic and intersection characteristics, and accident potential of different left turn treatments.

Geometric, turning movement counts, and traffic signal phasing data were collected at 100 intersections in Iowa using a questionnaire sent to municipalities. Not all questionnaires resulted in complete data and ultimately complete data were derived for 63 intersection providing a database of 248 approaches. Accident data for the same approaches were obtained from the Iowa Department of Transportation Accident Location and Analysis System (ALAS). Regression models were developed for two different dependent variables; 1) the ratio of the number of left turn accidents per approach to million left turning vehicles per approach., and 2) the ratio of accidents per approach to million traffic movements per approach.

A number of regression models were developed for both dependent variables. One model using each dependent variable was developed for intersections with low, medium, and high left turning traffic volumes.

As expected, the research indicate that protected left turn phasing has a lower accident potential than protected/permitted or permitted phasing. Left turn lanes and multiple lane approaches are beneficial for reducing accident rates, while raised medians increases the likelihood of accidents. Signals that are part of a signal system tend to have lower accident rates than isolated signals.

The resulting regression models may be used to determine the likely impact of various left turn treatments on intersection accident rates. When designing an intersection approach, a traffic engineer may use the models to estimate the accident rate reduction as a result of improved lane configurations and left turn treatments. The safety benefits may then be compared to any costs associate with operational effects to the intersection (i.e., increased delay) to determine the benefits and costs of making intersection safety improvements.

**Acknowledgments**

*Impacts on Safety of Left-Turn Treatments at High Speed Signalized Intersections* was a research project funded by the Iowa Highway Research Advisory Board. The Principle Investigator of the project was Dr. Tom Maze, Director of the Iowa Transportation Center and Professor of Civil Engineering at Iowa State University. Joe Henderson, Transportation Specialist at the Iowa Transportation Center, and Raji Sankar, Graduate Research Assistant in the Civil Engineering Department at Iowa State University also contributed to this project.

The project advisory committee comprised of: Tim Mrozek, City of Waterloo; Jim Thompson, Director of Traffic and Transportation at the City of Des Moines; Jim Hogan, Federal Highway Administration; Jim Brachtel, City Traffic Engineer with the City of Iowa City; Fred Walker, Bureau of Transportation Safety at Iowa Department of Transportation; and Dwight Stevens, Office of Maintenance at Iowa Department of Transportation. The researchers would like thank the committee members for their assistance.

The researchers appreciate the assistance provided by city traffic engineers in the data collection process. It would be too numerous to name them all, however, all of their help is acknowledged. Mr. Scott Moreland, Iowa Department of Transportation, is thanked for providing accident data.

Dr. Leonard West, Leonard B. West Engineering, Inc., is thanked for reading and reviewing the draft of this report.

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## Executive Summary

This research project addresses issues involving safety impacts of common left-turn treatments at signalized intersections. Left-turn treatment design decisions are usually based on an engineer's experience, judgment, and local standards. There are, however, no quantitative guidelines for estimating the safety impacts of alternative left-turn treatments while designing.

The objective of the research was to quantify the relationship between traffic volume, intersection characteristics, and the accident potential of alternative left-turn treatments. Although prior researchers have studied the positive and negative benefits of alternative left-turn treatments, the literature review reveals there are no quantitative models relating the accident potential of alternative left-turn treatments to intersection geometry and traffic volumes. Furthermore, there has been no published studies of any kind on left-turn treatments using Iowa data.

To generate a database for safety analysis of left-turn treatments two types of data were necessary - intersection data and accident data. Intersection geometry, traffic volume, traffic signal phasing, and timing data for 109 intersections were collected through a questionnaire sent to several city traffic engineers throughout Iowa. Accident data were obtained from Iowa's statewide accident database (Accident Location and Analysis (ALAS)) database maintained by the Iowa Department of Transportation. Two databases were developed: one for intersection data and another for accident data. Because complete data were not receive for all 109 intersections, not all were used in the analysis. In addition, because left-turn treatment is a function of the intersection approach, the data compiled resulted in 248 approaches with complete data.

Data analysis was performed for the 248 approaches. Dependent variables in the statistical modeling process were left-turn accident rate and approach accident rate. The independent variables were traffic volumes, left-turn treatment, and other characteristics of the intersection. The data were divided into five groups based on daily approach left-turn volume. A model for left-turn accident rate and another model for approach accident rate were developed for each of the five groups resulting in 10 different models. The relation between different variables in the model are illustrated by graphs.

The models can be used when choosing left-turn treatment at an intersection. Left-turn accident rate as well approach accident rate can be estimated by using the models. The models can be used to determine safety impacts of a change in left-turn treatment. For, example, the model can be used to determine the change in accident rate when the left-turn phasing at an approach is changed from protected-only to permitted phasing.

# CHAPTER 1

# INTRODUCTION

Left-turn traffic is a major source of conflicts at intersections. Though an average of only ten to fifteen percent of all approaching traffic turns left, left-turning vehicles are involved in approximately 45 percent of all accidents (1). This research project addresses issues related to safety of left-turn treatments at high speed signalized intersections.

Left-turn treatment design decisions are usually made based on an engineer's experience, judgment and local standards. For example, a municipality may use protected phasing for all left-turn movements where approach speeds are above a predetermined threshold. There are, however, no quantitative methods for estimating the safety impacts of left-turn design decisions. For instance, when an engineer considers changing a protected signal phasing at an intersection approach, a quantitative model would be useful to estimate the effect on the intersection of this change based on conditions existing at that intersection.

This research project has developed quantitative models to estimate accident implications of a change in left-turn treatment at intersections based on conditions existing at high speed signalized intersections. High speed signalized intersections were selected for this study because of their significant facility costs and larger traffic volumes. High speed signalized intersections are defined as intersections that have approaches with speed limits of 35 miles per hour or higher.

A prerequisite step in the research was the development of a database including intersection geometrics, traffic volumes, and traffic signal operating characteristics for major high speed intersections in Iowa. The primary purpose of the database was to help find the accident implications of left-turn treatments. However, it is anticipated that, in the future, the database will be used to investigate other intersection traffic control and safety issues.

## Background Information

The left-turn maneuver at an intersection is associated with traffic conflicts. Left-turning vehicles take longer to clear an intersection than through vehicles (2). Therefore, left-turning vehicles reduce the capacity of an intersection (3). When traffic volumes are low, left-turning vehicles find gaps in the opposing traffic and make left-turns. However, high traffic volumes on the opposing approach makes it harder for left-turning vehicles to find gaps to complete the left-turn maneuver. Consequently, both left-turning traffic, and through traffic, queued behind the left-turning vehicles, experience delays before clearing the intersections. Long delays sometimes result in drivers making dangerous maneuvers which may lead to accidents (4). Left-turns at an intersection can be controlled by the left-turn signal phase, and by providing left-turn bays.

## Left-Turn Lanes

A left-turn lane is an auxiliary lane for storing left-turning vehicles, thus, clearing the way for through traffic. The presence of a left-turn lane at a signalized intersection improves intersection safety and efficiency of operation (5), and the visibility for left-turning motorists (4). The overall traffic capacity of the intersection will be improved by providing a left-turn bay, which may decrease delay, fuel consumption, and probably decrease the number of accidents at the intersection (6). An exclusive left-turn lane may facilitate future installation of protected only left-turn phasing by separating left-turning traffic from through traffic. Constraints on the addition of a left-turn lane are space and the cost of installation.

**Left-Turn Signal Phasing**

Left-turn signal phasing is added to remove left-turn conflicts at intersections. The main purpose of left-turn phasing is to minimize accidents due to left-turn movements without substantially increasing overall delay at the intersection. A left-turn phase generally requires longer cycle lengths. As the number of phases is increased, the delay and fuel consumption also increase. The capacity of the intersection is reduced with an additional phasing because, with the addition of left-turn phases, the amount of green time available for all the other phases is reduced. Increased delay results because of additional lost time associated with starting delays, additional yellow intervals, and sometimes, longer cycle lengths (7).

**Permitted, Protected, and Protected/Permitted Left-Turn Phasing**

Left-turn phasing can be categorized into the following three groups: permitted left-turn phasing, protected left-turn phasing and protected/permitted left-turn phasing (4). Permitted or unprotected left-turn phasing occurs whenever an exclusive left-turn phase is not provided for left-turning vehicles. Left-turns are on the green ball made when there are gaps in the opposing traffic. Protected only left-turn phasing provides an exclusive phase for left-turns without any conflicting movements. This is indicated by a green arrow. Left-turns are prohibited during the rest of the cycle. Protected/permitted phasing is a combination of protected and permitted phasing. The left-turn signal phasing provides a protected phase for turning during one interval and allows turns to be made through gaps in the opposing traffic during another interval.

**Leading and Lagging Schemes**

Leading and lagging left-turns are two alternatives for protected left-turn phasing. In the leading left-turn sequence the protected left-turn arrow precedes the green interval for through traffic. In the lagging left-turn phase the protected left-turn arrow follows the green interval for through traffic.

A leading left-turn phase reduces conflicts between left-turning vehicles and opposing through vehicles by clearing the left-turning vehicles first. This is preferable when there is considerable left-turning traffic and there is no left-turn lane(8). Leading left-turn phasing sometimes results in left-turning vehicles continuing to turn even after the end of the protected phase without giving right-of-way to opposing through traffic. With a lagging left-turn phase, left-turning vehicles do not preempt the right-of-way of opposing through traffic. Lagging left-turn phasing also makes pedestrian crossing easier (8).

**Accidents Associated with Different Types of Left-Turn Phasing**

Protected left-turn phasing has the drawback of increasing delay for left-turning vehicles because motorists turning left have to wait for a green arrow (protected turn) even though there may be gaps in the opposing traffic stream. While protected-only phasing reduces the number of left-turn accidents, it may increase the number of rear-end accidents (4).

Permitted left-turn phasing does not allow an exclusive phase for turning left. Left-turning vehicles may turn in front of opposing traffic, resulting in left-turn accidents. Permitted phasing reduces intersection delay at the cost of increasing accidents.

Protected/permitted left-turn phasing occurs when the left-turners are first provided with a protected phase and then also allowing traffic to make left-turns through gaps in on-coming traffic during the through traffic phase. Protected/permitted phasing gives the motorists more freedom to make left-turns than protected left-turn phasing. In comparison to protected phasing, protected/permitted phasing decreases the delay but it also increases the number of left-turn accidents. Less delay results in fewer rear-end accidents. Generally, protected/permitted is safer than permitted only phasing (4).

**Research Objective**

The objective of the research project is to quantify the relationships between intersection and traffic characteristics, and accident reduction potential of modified left-turn treatment. Characteristics that were included in the analysis were:

- Intersection geometry
- Traffic volumes
- Traffic signal phasing
- Approach speed

Relationships between left-turn accidents and left-turn treatments were found using inferential statistics. These relationships provide traffic engineers with a quantitative framework to make tradeoffs between accident potential and left-turn treatments.

## Methodology

The research involved the following steps:

- Literature review: A detailed review of past research in the field of left-turn treatments, their safety, and to determine gaps in the literature.

- Data collection: This consisted of collecting intersection geometry and traffic control information obtained from city traffic engineers and the Iowa Department of Transportation. Accident reports were obtained from the Accident Location and Analysis Database maintained by the Iowa Department of Transportation.

- Database development: Data collected were coded into two microcomputer databases. One database contains information on intersection geometrics and traffic volumes. The other database is comprised of the accident data.

- Data analysis: The database was transferred to Iowa State University's mainframe computer for statistical analysis. The statistical analysis was performed using the computer package Statistical Analysis System (SAS). Models were developed to estimate the relationships between accident rates, traffic volumes, and several types of left-turn treatments.

- Findings: The findings of the statistical analysis were interpreted so that the relations developed could be used for field applications.

## Organization of the Report

A detailed literature review and gaps found in the literature are presented in Chapter 3. Intersection geometry, traffic volumes, and traffic control information data were collected by sending questionnaires to city traffic engineers. Findings of this research are reported in Chapter 4. This chapter also demonstrates the use of the research for practical application with an example. Conclusions and recommendation for future research on the issue of left-turn treatment are presented in Chapter 5.

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# CHAPTER 2

# LITERATURE REVIEW

The objective of the literature review is to study past research on the topic of left-turn treatment and accident reduction, and identify gaps in literature. A computerized literature review was conducted using the Transportation Research Information Service (TRIS) database. Articles dealing with safety/accidents, signalized intersections, left turns, and left-turn phasing were surveyed. *Transportation Research Records* served as a valuable source of articles on left-turn treatment and accidents. Some of the articles were federal and state department of transportation reports.

The literature review revealed that although there are several articles on left-turn treatment, none of them have produced a model predicting accident implications of modifying the left-turn treatment. No research on left-turn treatments using data from intersections in Iowa was found.

Some of the studies have been before-and-after studies. Although before-and-after studies provide information on the impact on accident rates of a specific change, they do not determine the trade-offs between specific treatments, intersection characteristics, traffic volumes, and accident potential. A few studies have been conducted to develop warrants for left-turn phasing. There are no uniform warrants and guidelines for left-turn treatments.

## Studies on Left-Turn Treatment

There have been several studies on the safety of left-turn treatments. The different types of studies in this topic can be classified into the following groups:

- Before-and-after studies
- Comparison of intersections
- Warrant/Guidelines development studies

Before-and-after studies are those for which a time series of data are collected before and after a specific change is made to geometry or signalization of an intersection. To gain statistically significant estimates of the accident rate before and after the change requires data for up to three years before and three years after the change. Due to the data requirements of before-and-after studies, a limited population of intersections are considered.

Comparison studies investigate the accident rates at similar intersections with different left-turn treatments using cross-sectional data. In comparison studies, data are collected for a large number of intersections over a short period of time.

## Studies on the Safety Effects of Left-Turn Lanes

Hammer conducted a before-and-after study of 53 urban and rural intersections in California to investigate the safety impacts of adding a left-turn lane (1). He found the installation of left-turn lanes resulted in significant reduction in accidents. The installation of a left-turn lane resulted in a 54 percent reduction in left-turn accidents and 17 percent reduction in total number of accidents at signalized intersections.

Foody and Richardson analyzed accident experience over a two year period on 363 intersection approaches on rural state highways in Ohio to evaluate the safety effects of left-turn lanes (2). They classified approaches with respect to signalization, number of lanes, presence of left-turn lane, and intersection type. At signalized approaches with left-turn lanes, the left-turn accident rate was found to be 39 percent lower and the total accident rate was 9 percent lower. These differences were not statistically significant at the five percent level.

Five years of accident data for intersections in Lexington, Kentucky, were used to compare accident rates at intersections with and without left-turn lanes (3,4). The study defined left-turn related accidents as: (a) a left-turning vehicle turns into the path of an oncoming vehicle, (b) a left-turning vehicle that is struck from behind while waiting to turn left, and (c) a vehicle that weaves around a vehicle stopped waiting to make a left-turn and is involved in an accident. The study determined that the left-turn accident rate is significantly lower for intersections with left-turn lanes when compared to intersections without left-turn lanes. For signalized intersections with left-turn lanes, the left-turn accident rate was 54 percent lower. The left-turn accident rate dropped further with the addition of a left-turn phase.

In their study to determine the relation of accidents to geometric features of highways, David and Norman used data from 558 intersections (5). They concluded left-turn lanes primarily serve the purpose of improving capacity at an intersection. They did not find left-turn lanes act as an accident reduction measure. In fact, they found that accidents at intersections with left-turn lanes were more frequent (significantly more frequent) when compared to intersections without left-turn lanes. The decrease in left-turn accidents is more than offset by the increase in accidents involving through traffic. These results conflict with the results of the previous studies showing left-turn lanes significantly reduce accident rates.

McCoy and Malone studied the safety effects of "Left-Turn Lanes on Urban Four-Lane Roadways" (6). Their objective was to develop a definitive guide recommending when left-turn lanes should be implemented at intersections on urban roadways in Nebraska with projected daily hourly volumes (DHV's) between 600 and 1800 vehicles per hour (vph). Accident rates for approaches with left-turn lanes were compared to those without. The types of accidents that were compared are: (a) right angle, (b) rear-end, (c) sideswipe (same direction), (d) sideswipe (opposite direction), (e) head-on, (f) left-turn, and (g) right-turn. The presence of left-turn lanes was not found to be associated with a statistically significant reduction in the number of sideswipe (opposite direction), head-on, or right-turn accidents. However, the presence of left-turn lanes on signalized approaches was associated with statistically significant reductions in rear-end, sideswipe (same direction), and left-turn accident rates.

**Studies on Accident Rates for Raised Medians**

Squires and Parsonson conducted a study on accident comparisons of raised median and two-way left turn lane median treatments (7). They found that raised medians have lower accident rates for most conditions. However, two-way left-turn lanes had lower accident rates where a few concentrated areas of turns existed. Approaches with raised medians have accident rates which are about 40 percent lower than approaches with painted medians. This was attributed to the fact that 44 percent of approaches with raised medians have left turn lanes, therefore the reduction in accidents may be partly explained by the left turn lane.

**Studies on Left-Turn Phasing**

Agent conducted a study of protected/permitted phasing for the state of Kentucky (8). In a before-and-after accident analysis, he found that protected/permitted phasing resulted in a reduction in average total accidents per year per approach compared to the previously used left-turn treatment. Left-turn accidents, however, depended on the type of phasing present before the protected/permitted phasing was added. For a new signal installation, or when protected/permitted phasing was the first left-turn treatment (previously there was no left-turn signal), there was little effect on left-turn accidents, and there was a reduction in the number of total accidents. However, there was a large increase in left-turn accidents when protected/permitted phasing replaced protected-only phasing. Analysis also showed that protected/permitted phasing was more effective in reducing the accident rate for approaches without a separate left-turn lane than for approaches with a left-turn lane. For speed limits of 35 miles per hour or less, the number of left-turn and total accidents decreased slightly after the installation of protected/permitted phasing. For speed limits of 40 and 45 miles per hour, the "after" data showed an increase in accidents, especially left-turn accidents. For speed limits above 45 miles per hour, there was a dramatic increase in accidents. A comparison of approaches with and without the regulatory sign " LEFT-TURN YIELD ON (GREEN BALL)" revealed that the presence of the sign did not decrease the related accident rate. In fact, intersections without the sign actually had fewer related accidents than intersections having the regulatory sign.

Operational and safety characteristics of leading and lagging left-turn phases were compared in Arizona (9). One of the measures of effectiveness included in the study was intersection delay. The results of the study indicate that lagging left-turn phasing resulted in greater delay per vehicle compared to leading phasing. The study did not find any need to have consistent phasing throughout the state. No significant differences in left-turn accident history between leading and lagging operation were found. The study found that lagging left-turns are preferred by motorists.

Upchurch, Radwan, and Dean conducted a study on different types of left-turn signal phasing (10). The study made recommendations for comparing different types of left-turn phasing with respect to relative safety and operating characteristics. The safety performance and delay costs were evaluated for different types of left-turn phasing for a particular intersection. The traffic engineer is then allowed to make the judgment on the safety and delay tradeoff to select the best left-turn treatment for the intersection. The left-turn accident rate, according to the study, is the most appropriate accident rate for comparison of different left-turn phasing. Operating characteristics that could be used to compare different types of left-turn phasing were suggested as: (a) delay to all the vehicles approaching the intersection, (b) delay to through and right-turning vehicles, (c) delay to left-turning vehicles, (d) average or maximum queue length, (e) number of stops per vehicle, (f) vehicle operating cost, (g) fuel consumption, and (h) vehicle emission. The costs for each of these factors could be calculated using output from NETSIM. They suggest that an analysis of the various costs, mentioned above, be done for each type of left-turn phasing for a particular intersection. The costs and safety performance of each left-turn phasing should be evaluated and the engineer should be allowed to make a judgment on the safety and delay tradeoffs to select the best left-turn treatment.

**Before-and-After Studies**

Agent studied the effect of replacing protected left-turn phasing with protected/permitted left-turn phasing at four trial intersections (11). A before-and-after study was conducted for intersection delay and accidents. He concluded that protected/permitted left-turn phasing resulted in a 50 percent reduction in left-turn delay when compared to protected phasing. Left-turn accidents, however, increased with a change from protected to protected/permitted. For opposing volumes over 1,000 vehicles per hour on a four lane street, very few left-turns are made during the permitted phase. A benefit cost analysis "using the average annual cost for three year after period" showed that all the four locations had benefit-to-cost ratios greater than 1.

Warren conducted an accident analysis of left-turn phasing for intersections in the metropolitan area of Washington, D.C. (12). He evaluated two types of left-turn control changes listed below:

- Change from protected to protected/permitted.
- Introduction of protected/permitted phasing at signalized intersections that previously had no left-turn signals.

He analyzed the number of accidents before and after the change and compared them to the number of accidents at similar intersections that were not changed. The results of the study show that protected/permitted left-turn phasing effects the type of accidents. The change in the type of accidents depended on the type of left-turn phasing before the change to protected/permitted phasing. At intersections that previously did not have a left-turn phase (permitted phasing), rear-end and total accidents decreased while left-turn accidents increased by less than one per year. At intersections that had protected phasing and were converted to protected/permitted phasing, rear-end and total accidents decreased. Left-turn accidents, however, increased by 50 percent. Warren concluded that protected/permitted left-turn phasing was a better left-turn treatment than protected phasing. He justified this by the fact that the slight rise in the increase in the number of overall accidents is insignificant when compared to the savings in delay.

Upchurch compared left-turn accident rates for five types of left-turn phasing: permitted; leading protected/permitted; lagging protected/permitted; leading protected; and lagging protected (13). A database of 523 intersection approaches in Arizona was created. Left-turn accident rates were compared to determine the relative safety of different types of left-turn phasing. He made the following observations:

- The leading exclusive phase has the lowest left-turn accident rates.
- When there are two opposing lanes, lagging protected/permitted has the worst accident late.
- For permitted, leading protected/permitted, lagging protected/permitted, and leading protected with opposing lanes of traffic, the accident rate decreases as the left-turn volume increases.

A before-and-after study was also done. He observed that conversions resulting in decreases in left-turn accident rates were:

- From permitted to leading protected,
- From permitted to lagging protected/permitted.
- From leading protected/permitted to lagging protected/permitted.
- From leading protected/permitted to protected.

The conversions that resulted in increases in the left-turn accident rate were:

- From permitted to leading protected/permitted.
- From leading protected to leading protected/permitted.
- From leading protected/permitted to permitted.

## Warrants/Guidelines for Left-Turn Treatment

Members of the Colorado/ Wyoming Section of the Institute of Transportation Engineers (ITE) conducted a questionnaire-type survey to determine the techniques used to decide when a left-turn phase should be installed at a signalized intersection (14). One thousand two hundred questionnaires were mailed to ITE members. About 300 were returned and 164 responses indicated that a warrant for left-turn phasing had been adopted. The specific warrants used by each of the 164 respondents were classified into 30 different categories. Most of the warrants were based on delay, accident experience, and turning volumes. A need for a national standard for left-turn phasing was demonstrated.

Upchurch and Matthias studied the signal warrants for the state of Arizona (15). The study was conducted because there was no uniform method for application of left-turn phasing in Arizona. A warrant was developed to choose the appropriate type of left-turn signal phasing. Six arterial signalized intersections in the Phoenix metropolitan area were observed. Traffic volume and delay were determined using time-lapse photography. The effect of the type of left-turn signal phasing on left-turn delay and through delay was analyzed. For intersections with two opposing lanes protected phasing has higher left-turn delays than permitted phasing. They also found that through delay is small for permitted phasing when compared to protected/permitted and protected phasing. Protected/permitted phasing was found to decrease the delay for through vehicles by about four to eight seconds as compared to protected phasing. A warrant was developed on the basis of left-turn volume (hourly) 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. This warrant applies only to intersections with separate left-turn lanes.

Agent recommends that protected/permitted phasing (should not be used if any of the conditions exist (16):

- Speed limit is over 45 miles per hour.
- Protected-only phasing is currently in operation and speed limit is over 35 miles per hour.
- Left-turn movement must cross three or more opposing through lanes.
- Intersection geometrics force the left-turn lane to have a separate signal head.
- Dual left-turn lanes exist on the approach.
- A left-turn accident problem exists at the intersection.

He recommends that when protected/permitted phasing is used, the signal head for left-turn traffic should be located above the line separating the left-turn lane from the adjacent through lane so that left-turning traffic does not have a separate signal head. No regulatory sign was found to be necessary.

A similar set of guidelines is found in a Florida study (17). Some of the guidelines are:

- Protected/permitted phasing should be used whenever a left-turn phase is required unless there is a strong reason for using another type of left-turn phasing.
- Protected left-turn phasing should be used for an approach if any one of the following conditions exist:
- Double left-turn lanes
- Geometric restrictions
- Sight distance restrictions
- Approach is lead portion of lead/lag phasing sequence

**High Speed Signalized Intersections**

Washington, Gibby and Ferrara identified characteristics at some California high-speed signalized intersections that relate to accident rates (18). Effects of advance warning, signal timing and phasing, channelization, signal equipment configurations, shoulder widths and types, median widths and types, and approach speeds were studied. A database of high-speed isolated signalized intersections in California was developed. Two variables in the database which deal with left-turn movements on an approach were the presence or absence of a left turn phase and the presence or absence of left-turn lane. The presence of a separate left-turn phase appeared to reduce accidents at high speed isolated intersections. Vehicles on an approach without a separate left-turn phase would more likely be involved in a left-turn accident with opposing traffic. The existence of both left turn lane and phase resulted in a 70 percent decrease in the approach accident rate as compared to approaches without them. Rear-end accidents, directly associated with the existence of a left-turn lane was 37 percent lower. Left-turn accidents, related to the existence of a left-turn phase, were observed to be 85 percent less frequent. If a left turn lane is added to an intersection, a separate phase should also be added. They concluded that presence of advance warning sign with a flashing beacon, presence of a separate left-turn phase, presence of raised median, and wide paved shoulders lead to lower accident rates.

Agent did a study on traffic control and accidents at rural high speed intersections (19, 20). The objectives of the study were to determine the type of traffic control at rural high speed intersections, types of accidents occurring there, the factors that contribute to the accidents, and to recommend traffic control measures to decrease accident potential at these intersections. Sixty five intersections were studied. Forty-six of these were signalized. Others were stop sign controlled. Accident analysis was done to compare the three types of right-of-way control: (a) a stop sign with no intersection beacon, (b) a stop sign with intersection beacon, and (c) a traffic signal. The combined accident rates at intersections which have either a traffic signal or a stop sign (with or without intersection beacon) were very similar. Intersections having traffic signals and a high accident rate also have a large number of opposing left-turn accidents. The percentage of angle accidents was much lower at signalized intersections when compared to stop controlled intersections. The study concluded that providing the driver adequate warning of the intersection is of primary importance. At signalized intersections, providing a proper change interval and maximizing the visibility of signal heads are essential. A separate left-turn phasing is also recommended.

Review of literature demonstrates that there is a great diversity in guidelines being used for left-turn treatments. Kentucky, Florida and Arizona have their own set of guidelines. The criteria used most frequently, for the choice of a left-turn phase, are delay, traffic volume, and accident experience. Other factors, such as, intersection geometry, presence of raised medians, approach grades are not usually considered.

The gaps in the literature can be summarized as:

- There is no empirical model for estimating left-turn accidents based on left-turn treatment and characteristics specific to an intersection.
- No left-turn study using data from Iowa has been found.

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# CHAPTER 3

# DATA COLLECTION AND ANALYSIS

## Data Collection

Four types of data were collected for this project. These data include, 1) intersection geometry, 2) traffic volumes, 3) signal phasing, and 4) accident data. Intersection geometry, traffic volume, and signal phasing data were collected by sending questionnaires to several municipalities across Iowa. A sample questionnaire is contained in Appendix A. One hundred and fifty questionnaires were sent to Iowa municipalities. Data for 109 intersections were obtained. Geometric and signal data were obtained for all intersections. Traffic volumes, however, were available for only 63 intersections.

## Accident Data

Accident data for five years (1987 -1991) were obtained for each intersection from the Accident Location and Analysis System (ALAS) database. ALAS is an accident database maintained by the Iowa Department of Transportation. It is comprised of accident reports submitted by law enforcement officers that are coded into the database.

The ALAS database contains the following information for each accident:

- Direction of travel of each vehicle involved in the accident.
- Vehicle action/maneuver.
- Age and gender of the drivers involved.
- Accident severity.
- Time of day that the accident occurred.
- Day of the week.
- Roadway conditions.
- Driver condition: inebriated or sober.

- Possible cause of the accident, for example: failure to yield right-of-way while making a left-turn.

## Database Development

The questionnaire data were coded by intersection into a microcomputer LOTUS 1-2-3 database. These data included intersection geometrics, signal characteristics, and traffic counts. The turning movement counts were in different formats. All the data were converted to a standard form before coding. For example, turning movement counts were obtained as evening peak hour, or 24-hour volumes. The peak hour turning movement counts were converted to annual average daily traffic (AADT) using procedures defined in the Iowa Department of Transportation and reported in "Automatic Traffic Recorders: 1982-1991." A sample of calculations to convert peak hour volumes to AADT is shown in Appendix B.

Accident data were coded into another database due to the complexity of the database containing intersection data. Left-turn accidents were identified from the ALAS database by going through each individual accident report. A left-turn accident is defined as any accident that involved a left-turning vehicle.

A third database was created so that information could be coded by approach. This is done because left-turn phasing is specific to an approach and not to an intersection. The characteristics included are presence or absence of median, left-turn lane, number of lanes, lane width, left-turn lane width, AADT, approach turning movement counts, accident history for five years, and whether the signalized intersection was part of a signal system or an isolated signal. All relevant data were available for 63 intersections resulting in 248 approaches.

**Data Analysis**

Two kinds of accident rates were developed for the analysis: the left-turn accident rate and the approach accident rate. The left-turn accident rate is defined as the number of left-turn accidents on the approach per million left-turning vehicles on the approach. Approach accident rate is the number of accidents per year on an approach per million entering vehicles.

**Statistical Modeling**

The database developed in LOTUS 1-2-3 was converted to ASCII format and downloaded to the mainframe computer for analysis on the Statistical Analysis System (SAS). The following independent variables were considered for the regression model:

- MEDIAN: Whether a raised or painted median is present. If a median is present, the value of the variable was 1, and 0 if not.
- SYSTEM: Whether the intersection is part of a signal system or not. If the intersection was a part of a system, the value of the variable is 2, and 1 if not.
- LANES: The number of lanes on an approach excluding the left-turn lane. The values ranged from 1 to 3.
- LLANES: The number of left-turn lanes. It is either 0 or 1. Dual left-turn lanes were not studied in this research project.
- WIDTH: The average width of through lanes. Values range from 9 to 15 feet.
- LWIDTH: The average width of left-turn lane. Values range from 9.5 to 12.5 feet.
- ALIGN: The alignment of opposing left-turn lanes. If opposing left-turn lanes are aligned the value is 1, and 0 if not. A value of 2 is assigned where a left-turn lane is not present.
- SPEED: The speed limit on the approach. Values range from 35 to 55 miles per hour.

- PERMIT: This variable indicates the presence of permitted phasing. The value of this variable is 1 for permitted phasing and protected/permitted phasing. It is 0 for protected phasing.
- PROTECT: This variable indicates the presence of protected phasing. The value of this variable is 1 for protected phasing and protected/permitted phasing, and 0 for permitted phasing.

- LVOL: The annual average daily approach left-turn volume. Values range from 0 to 11,000.

- TVOL: The annual average daily through volume on the approach. Values range from 0 to 13,265.

- RVOL: The annual average daily right turning volume on the approach. Values range from 0 to 8,820.

- TOTVOL: The annual average daily approach volume. This is the sum of left-turning, through and right-turning volumes. Values range from 369 to 18,061.

The independent variables are:

- LACCRATE: The left-turn accident rate. This is the number of left-turn accidents per million left-turning vehicles on the approach.

- ACCRATE: The approach accident rate. This is the number of accidents on an approach per million vehicles on the approach.

Various graphs were plotted to inspect the nature of relationship between the dependent and independent variables. This process was also used to determine outlying data points. Outlying data points, also known as outliers, are extreme data that are far removed from the rest of the data. The outlying data points were removed from the data set because they may distort the results. The outliers removed had high left-turn accident rates (greater than 10 left-turn accidents per million left-turning vehicles). Also approaches with speed limits less than 35 miles per hour were removed.

A Pearson's Correlation analysis was performed to determine which variables are correlated. Correlated variables could lead to multicollinearity. This occurs when the parameter estimates of the correlated variables changes drastically when one the variables is dropped. Also, the standard deviation of the parameter estimates of the correlated variables is very high. Therefore, correlated variables were removed. TVOL and RVOL were removed from the regression model because they are correlated with TOTVOL.

The number of independent variables were reduced because large models are difficult to understand and interpret. Some of the independent variables may be intercorrelated and add little to the predictive power of a model while substantially increasing the sampling variation of the regression coefficients. This may detract the model's descriptive abilities and increase the problem of round-off errors.

Regression was performed to fit linear and non-linear models, including a logit function. None of the attempted non-linear functions provided better results than a linear model. Therefore, a linear model was applied. After selection of the variables using forward, backward, and stepwise selection procedures, one model was obtained for all left-turn volumes. Left-turn volumes ranged from 0 to 11,000. The $R^2$ obtained from the model is very low: between 0.1 and 0.15. Due to the large variation in left-turn volumes, the data were divided into five groups of approximately similar sizes based on left-turn volumes. The groups are:

- Left-turn volumes of 0 to 500, which includes 38 data cases
- Left-turn volumes of 500 to 1,000, which includes 33 data cases
- Left-turn volumes of 1,000 to 1,500, which includes 29 data cases
- Left-turn volumes of 1,500 to 2,000, which includes 24 data cases
- Left-turn volumes over 2,000, which includes 33 data cases

The forward, backward and stepwise selection procedures were repeated to obtain models for both the dependent variables in each group of left-turning volumes. The findings are discussed in the next chapter.

# CHAPTER 4

# FINDING INTERPRETATIONS

Given the data included in the analysis database, there are clear gaps in the causal information related to traffic accidents. For example, the data set does not include information on weather conditions, pavement conditions, time of day of accidents, and lighting. During the winter, Iowa weather can be a pervasive factor in causing traffic accidents, including left-turn accidents. Because weather and other variables are not included in the database, the analysis assumes they remain equal in all cases. In other words, winter weather, site distance problems, pavement conditions, etc. are contributors to the cause of accidents uniformly at all locations. Because, in actuality, differences in conditions at specific locations do make a difference in the potential for accidents, some of the variance in accident rates is not accounted for in the variables included in the database. In fact, as will be seen in the analysis results, much of the variance in accident rate is not accounted for by the variables included in the database.

Given that an accident's causal factors are highly related to site specific conditions and conditions specific to the driver, then why conduct statistical analysis relating accident rate and intersection characteristics over a series of heterogeneous intersections? The reason for conducting the analysis is to provide the design engineer information on the level of safety benefits that may be expected from a safety enhancing left turn treatment in advance of constructing the improvement. In other words, the analysis seeks to determine the safety impacts of left turn improvements, assuming all other things remain equal. Accident reduction information can then be used to assist in making design modification decisions.

# RESULTS

Mathematical models of the accident rates are estimated using several functional forms. However, linear models provide statistical results that are as good as any found. Dependent variables for the regression models are the left-turn accident rate and approach accident rate. The left-turn accident rate represents the number of left-turn accidents on the approach per million left-turning vehicles. Approach accident rate is defined as the number of accidents on an approach per million vehicles on the approach. A model is determined with approach accident rate as the dependent variable in order to find the effects of left-turn treatment on other types of accidents at the intersection.

Initially, one model was estimated for all volumes. This single model has a very low $R^2$. Therefore, the data set is divided into five groups based on left-turning volumes.

In each group of left-turn volumes, a model for left-turn accident rate and another model for approach accident rate were estimated. The best results, in terms of $R^2$ and statistically significant parameter estimates, were obtained for the group that has left-turn volumes between 500 and 1,000 per day. Models estimated in other volume ranges resulted in parameter estimates that were not statistically significant and have very low $R^2$ values. These models are presented only for illustration purposes. The researchers only have confidence in the results of the models for the 500 to 1,000 vehicles per day range. For comparison purposes, the same independent variables were used for all groups.

The left-turn accident rate and approach accident rate models for the group with daily left-turn volumes between 500 and 1,000 are explained first. This is followed by models for the group with daily left-turn volumes of 1,500 to 2,000. The models for this group are similar to the models in the 500 to 1,000 group. The models for the other groups are presented for illustration only, and can be found near the end of this chapter.

**Regression Models: Daily Left-Turn Approach Volumes between 500 and 1,000**
**Left-Turn Accident Rate Model**

A linear regression model has been developed for the left-turn accident rate for daily left-turn approach volumes between 500 and 1,000. The dependent variable is the left-turn accident rate which is the number of left-turn accidents per million left-turning vehicles on the approach. The model is:

$$\begin{aligned} \text{LACCRATE} = 3.78 &- \underset{(0.043)}{2.24\ \text{SYSTEM}} - \underset{(0.012)}{6.48\ \text{LLANES}} + \underset{(0.021)}{0.50\ \text{LWIDTH}} + \underset{(0.133)}{1.74\ \text{PERMIT}} - \\ &\underset{(0.064)}{2.29\ \text{PROTECT}} + \underset{(0.006)}{0.00047\ \text{TOTVOL}} \end{aligned}$$

(Model 1)

Numbers shown in parenthesis are the level of significance of the parameter estimate.

Thirty-two data cases were used to estimate Model 1. The parameter estimates for SYSTEM, LLANES, LWIDTH, PROTECT, and TOTVOL are significant at the 10 percent level. The parameter estimate for PERMIT, however, is only significant at the 15 percent level. MEDIAN was not significant for use in this model. The $R^2$ for this model is 0.442.

This model shows that permitted phasing results in the highest left-turn accident rate as compared to protected and protected/permitted phasing. Protected phasing has a significantly lower left-turn accident rate as compared to protected/permitted and protected phasing. Figure 1 shows the effect of the three different types of left-turn phasing on left-turn accident rate. This figure is a graph of left-turn accident rate versus total approach volume. The assumptions made to construct Figure 1 include an approach at an isolated intersection with a 12 foot left-turn lane and two through lanes.

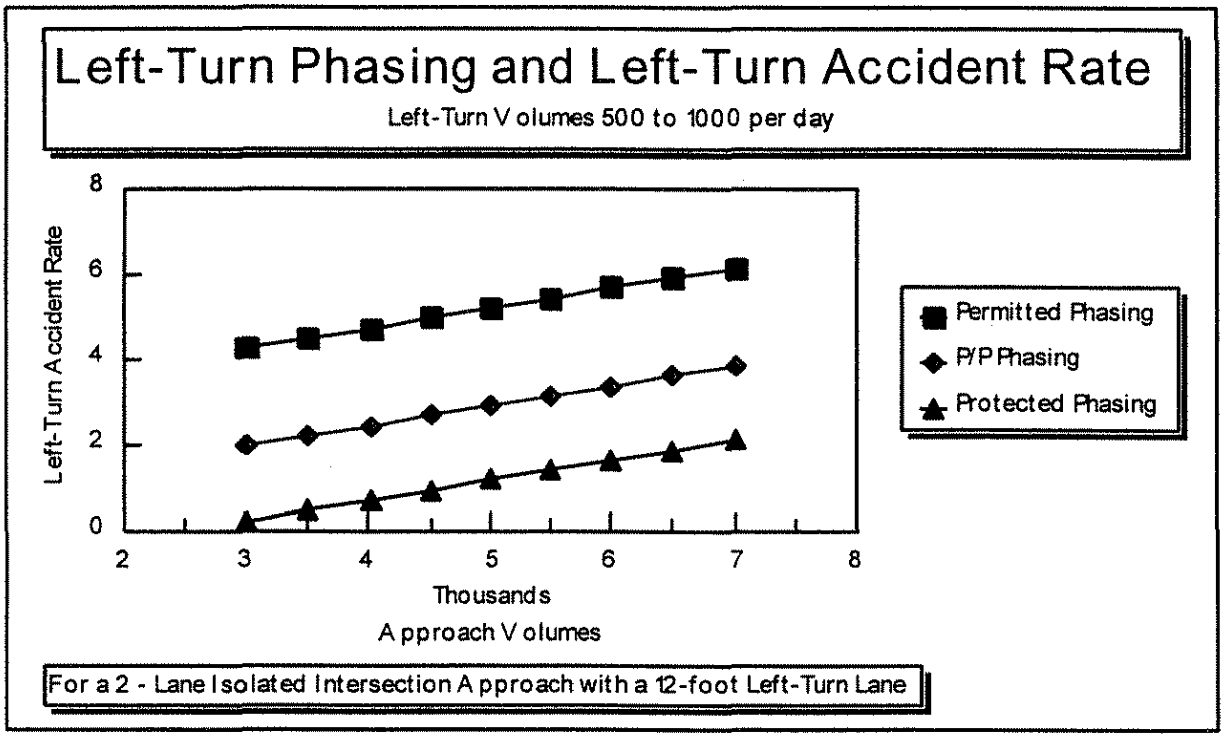


Figure 1: Effect of left-turn phasing on left-turn turn accident rate

The effect of a left-turn lane and whether a signal is a part of a signal system can also be shown using this model. Figure 2 shows the effect of a left-turn lane in reducing the left-turn accident rate for a two lane approach with and without a left-turn lane. Presence of a left-turn lane will reduce the number of left-turn accidents because protected and protected/permitted phasing are not normally used unless a left-turn lane is present. A left-turn lane separates left-turning vehicles from through vehicles and, therefore, reduces the left-turn accident rate. Figure 3 shows the effect of a signalized intersection being in a signal system. Signalized intersections that are part of a signal system exhibit significantly lower left-turn accident rates than intersections that are not part of a system. This may be due to the fact that a coordinated signal system can create a platooning effect reducing the randomness of vehicle arrivals, thereby promoting an efficient flow in the corridor.

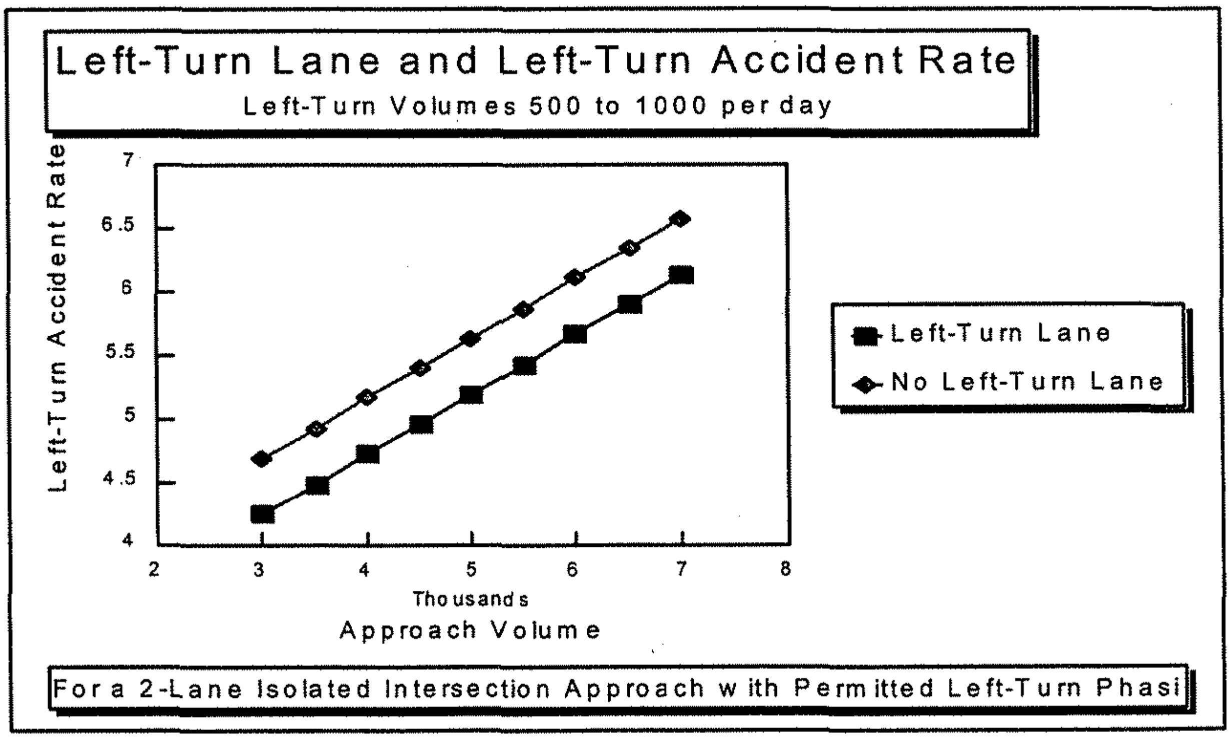


Figure 2: Effect of left-turn lane on left-turn accident rate

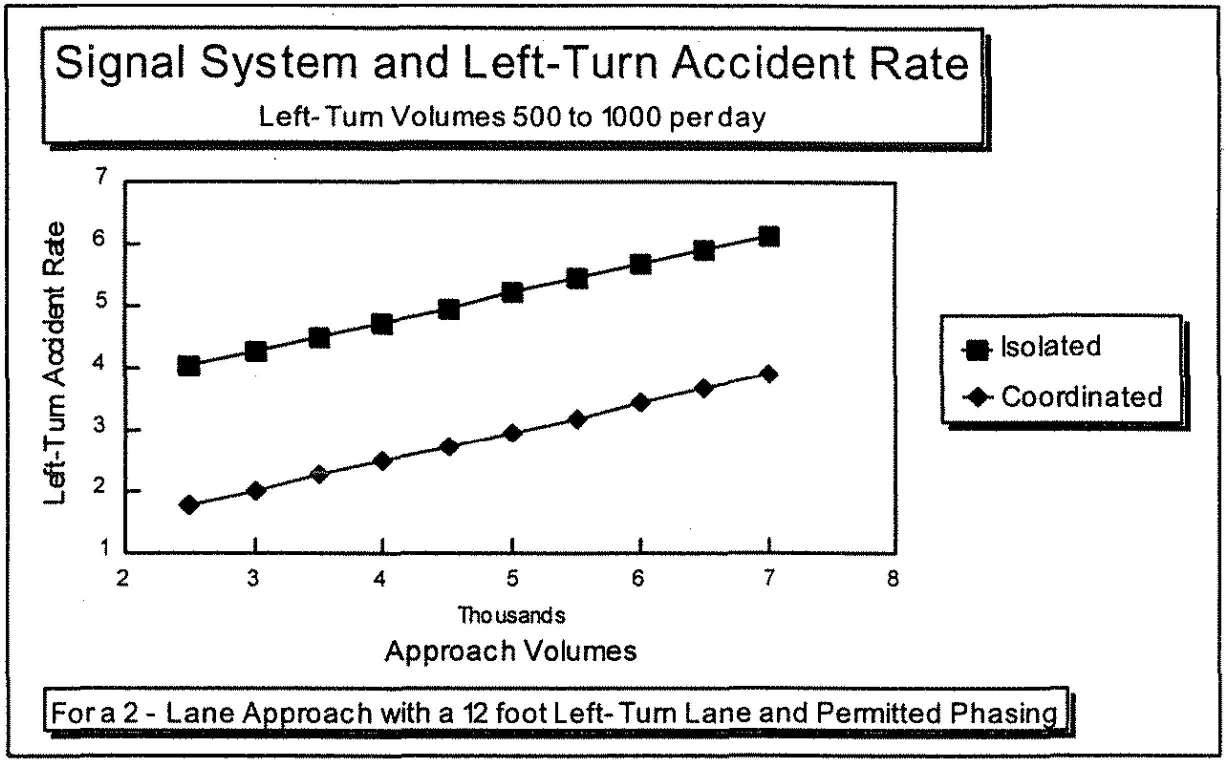


Figure 3: Effect of being in a system on left-turn accident rate

**Approach Accident Rate Model**

A linear regression model was developed for approach accident rate for daily left-turn volumes between 500 and 1,000. The dependent variable is approach accident rate which is the number of accidents on the approach per million vehicles. The model is:

$$
\begin{array}{lllll}
\text{ACCRATE} = 1.14 + 0.90\ \text{MEDIAN} & - 0.17\ \text{LANES} & - 3.09\ \text{LLANES} & + 0.26\ \text{LWIDTH} + \\
\qquad\qquad\quad (0.0017) & (0.3868) & (0.0001) & (0.0001) \\
\qquad\qquad\quad 0.11\ \text{PERMIT} & - 0.28\ \text{PROTECT} & - 0.000085\ \text{TOTVOL} & \\
\qquad\qquad\quad (0.6816) & (0.2949) & (0.0117) &
\end{array}
\qquad \text{(Model 2)}
$$

The parameter estimates for MEDIAN, LLANES, LWIDTH, and TOTVOL are significant at the 10 percent level. The parameter estimates for PERMIT and PROTECT, however, are not significant at the 10 percent level. They have been included in the model to determine the effects of left-turn phasing on approach accident rate. However, because of the low level of statistical confidence in some of the parameter estimates, little confidence is held for the overall model. The $R^2$ for this model is 0.678.

In the model, there are two variables representing the left-turn lane. One is LLANES, the number of left-turn lanes on an approach, and the other is LWIDTH, the width of the left-turn lane. The width of the left-turn lane was included in the analysis because there is variability in the width of the left-turn lane when it was present. The left-turn lane width ranged from 9.5 feet to 12.5 feet. When either of the variables, LLANES and LWIDTH, are removed due to their correlation, the models are not significant and the parameter estimates could not be interpreted. Best results were obtained by including both the variables in the model.

This model shows that permitted phasing results in the highest accident rate as compared to protected and protected/permitted phasing. Thus, protected left-turn phasing helps reduce left-turn accidents as well as the overall number of accidents on an approach. These results are similar to those for left-turn accident rate. Figure 4 shows the effect of left-turn phasing on the approach accident rate. It contains a graph of approach accident rate versus approach volume. Assumptions used to construct this graph include an approach with a 12 foot left-turn lane, two through lanes, and a median. It can be seen that the approach accident rate decreases at a very modest rate with increasing approach volumes. The decrease in accident rate with increased approach volumes seems counter intuitive. However, the very modest decrease may be due to a correlation between higher approach volumes and the use of improved left-turn treatments. For example, permitted left-turn phasing is more likely to be used on lower volume approaches while protected phasing is used on high volume approaches.

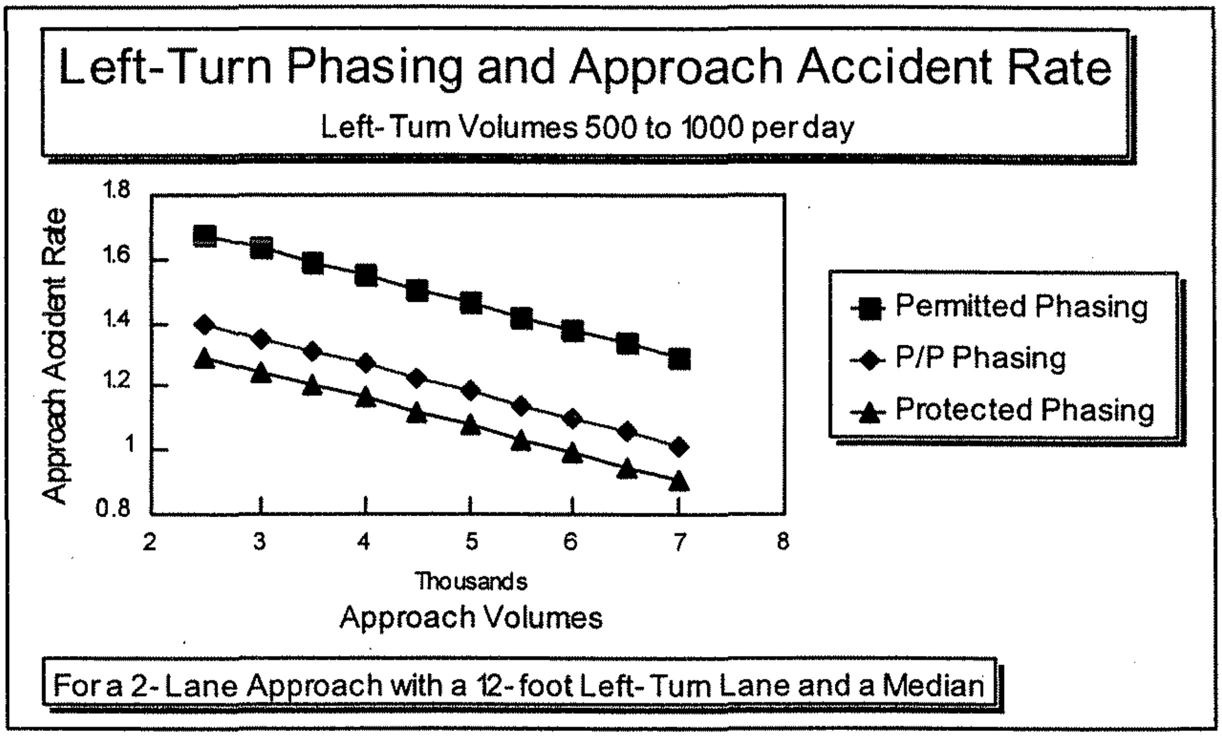


Figure 4: Effect of left-turn phasing on approach accident rate

As with the left-turn accident rate, a left-turn lane significantly lowers the approach accident rate. Figure 5 shows the effect of a left-turn lane on the approach accident rate. The model shows that a left-turn lane decreases accident rate. However, the width of the left-turn lane also needs to be considered. Assumptions for this figure include an approach with permitted phasing, two 12-foot through lanes, a 12-foot left-turn lane, and a median.

Figure 6 shows the effect of the number of through lanes on approach accident rates. The approach accident rate is lower for approaches with two through lanes compared to approaches with one through lane. Assumptions for this figure include an approach with no left-turn lane, permitted phasing and no median.

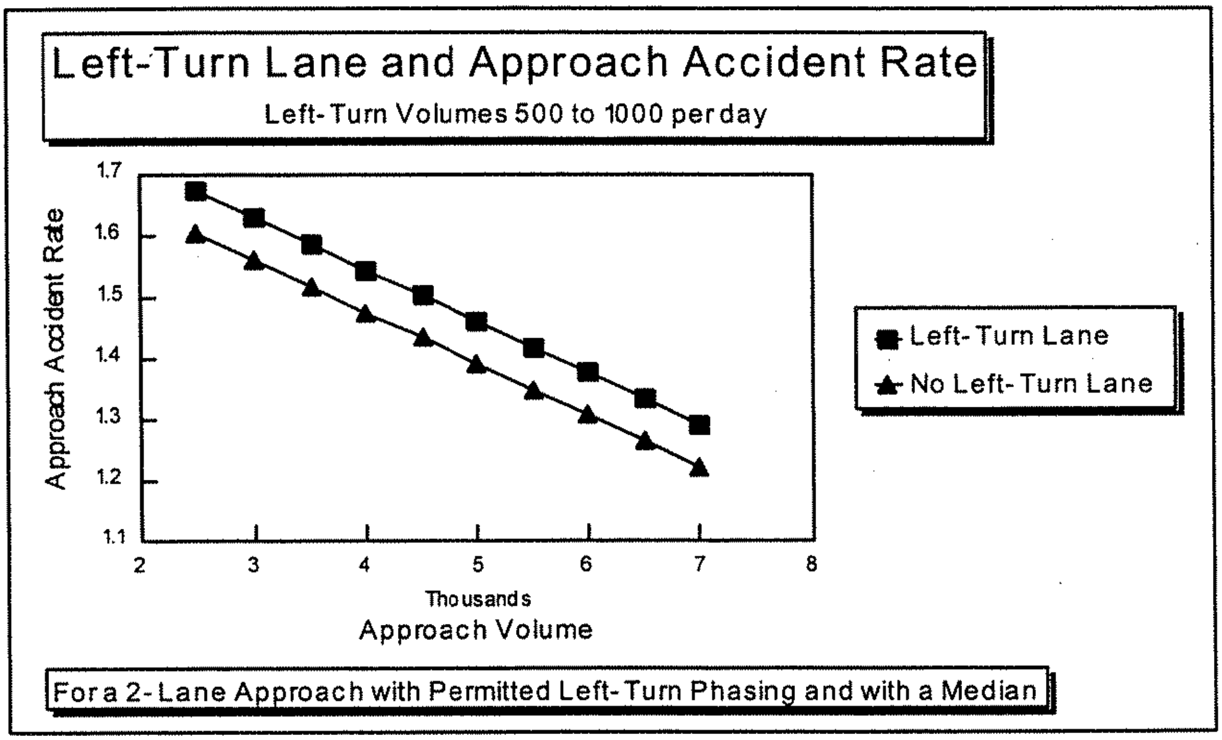


Figure 5: Effect of left-turn lane on approach accident rate

Figure 7 shows the effect of a median on the approach accident rate. It can be seen that the presence of a median increases the approach accident rate. This may be because some of the limitations of statistical modeling which are discussed later in this chapter.

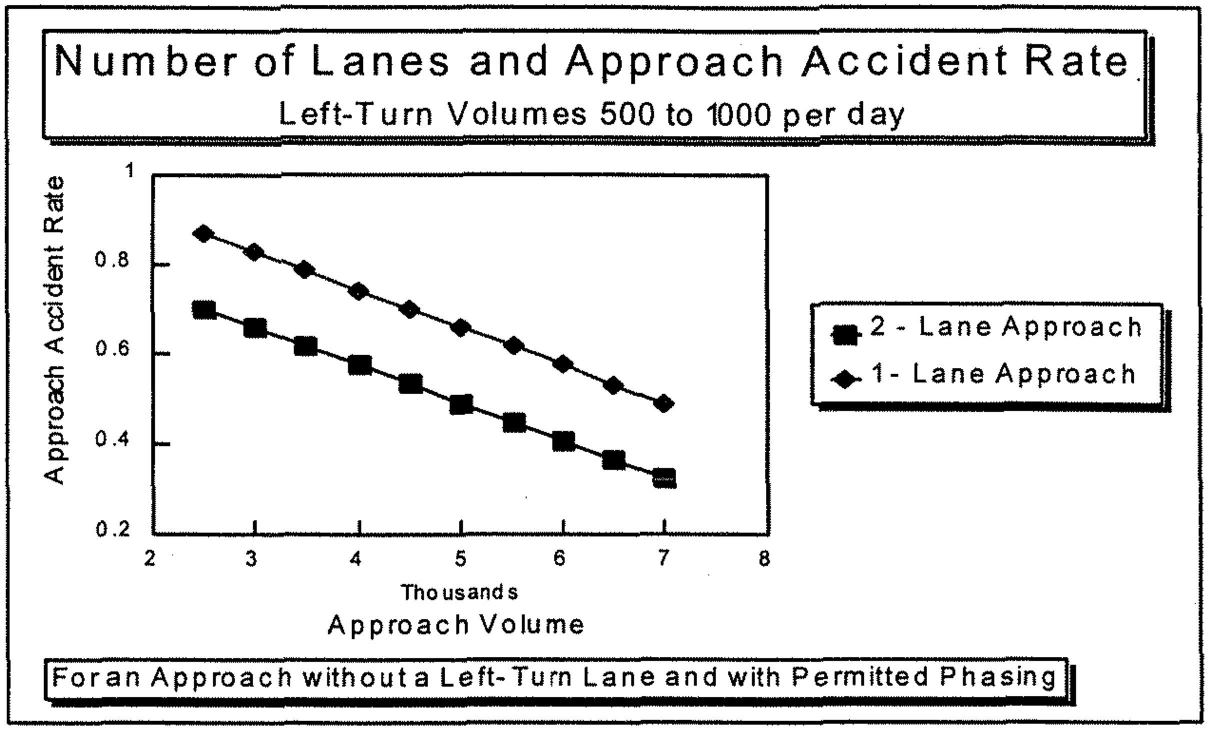


Figure 6: Effect of number of lanes on approach accident rate

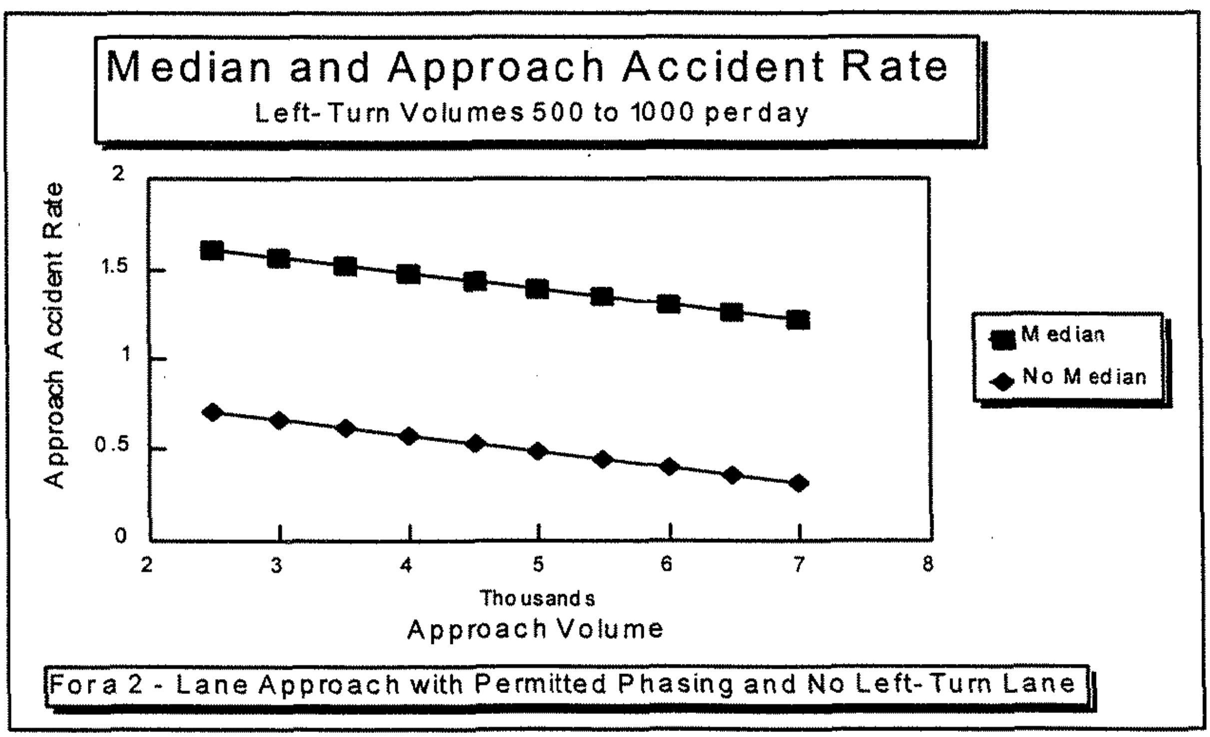


Figure 7: Effect of median on approach accident rate

**Regression Model: Daily Left-Turn Approach Volumes between 1,500 and 2,000**
**Left-Turn Accident Rate Model**

A linear regression model was developed for the left-turn accident rate for daily left-turn approach volumes between 1,500 and 2,000. The data set included 28 data cases. The dependent variable is the left-turn accident rate which is the number of left-turn accidents per million left-turning vehicles on an approach. The model is:

$$
\begin{aligned}
\text{LACCRATE} = 1.39 &+ \underset{(0.2410)}{0.98}\ \text{SYSTEM} - \underset{(0.1472)}{12.55}\ \text{LLANES} + \underset{(0.2344)}{0.85}\ \text{LWIDTH} + \\
&\underset{(0.8538)}{0.158}\ \text{PERMIT} - \underset{(0.6963)}{0.48}\ \text{PROTECT} + \underset{(0.1018)}{0.00017}\ \text{TOTVOL}
\end{aligned}
\qquad \text{(Model 3)}
$$

The parameter estimates for none of the variables are significant at the 10 percent level. However, the parameter estimates, with the exception of the parameter for the signal systems, are consistent with the Model 1. The $R^2$ for Model 3 is 0.365. Because of the low statistical confidence in the parameter estimates, little confidence is held for the overall model. However, the model results are indicative of overall trends.

Figure 8 contains a graph of left-turn accident rate and total approach volume. Permitted phasing has the highest left-turn accident rate and protected phasing the lowest left-turn accident rate among the three kinds of left-turn phasing. These results are similar to those found for left-turn volumes between 500 and 1,000. Assumptions used to make the graph include a two lane approach with a 12 foot left-turn lane, and an intersection that is part of a signal system.

The effect of presence of a left-turn lane and being part of a signal system were examined. Figure 9 illustrates the effect a left-turn lane on the left-turn accident rate. A left-turn lane lowers the left-turn accident rate. Assumptions made to construct the Figure 9 are an approach with two lanes, protected/permitted phasing, and an intersection that is part of a signal system. This result is consistent with Model 1.

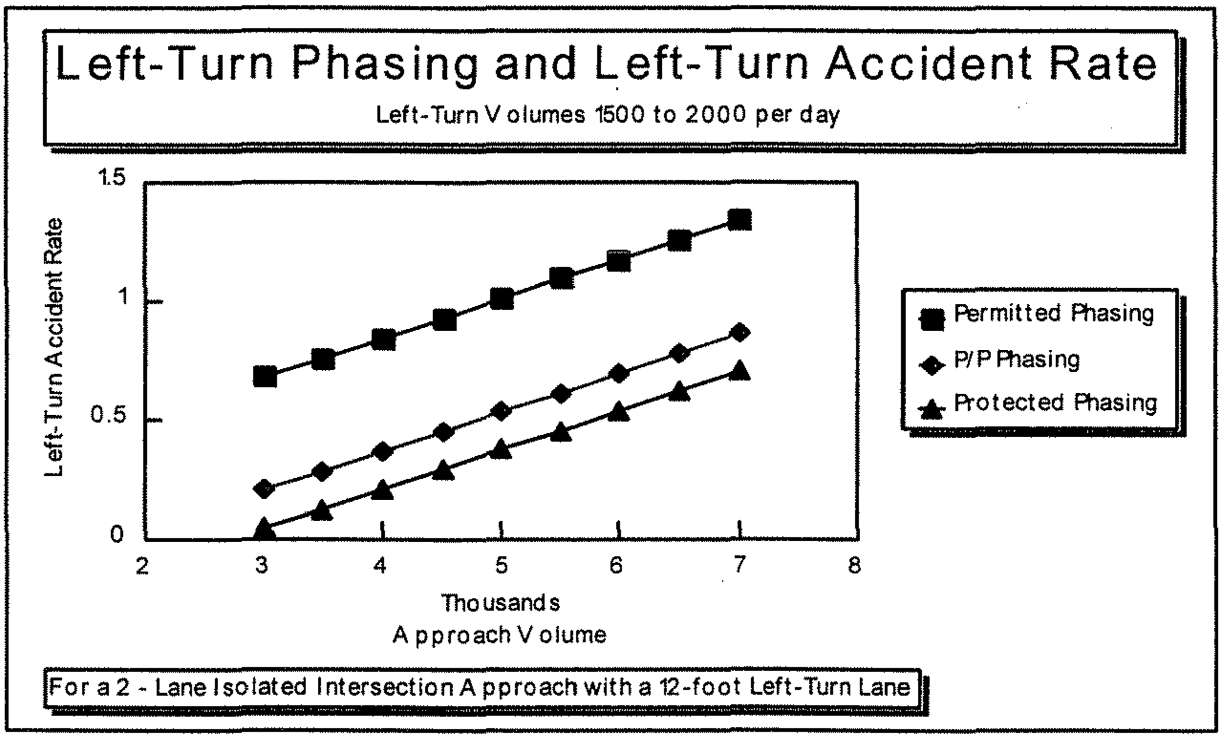


Figure 8: Effect of left-turn phasing on left-turn accident rate

The effect on accident rate for signals in a system was also investigated. In this model, the left-turn accident rates are higher for the approaches that are in a system as compared to those not in a system (See Figure 10). This is not consistent with the results for the same variable in Model 1. One of the reasons for this could be that the parameter estimate is not significant at the 10 percent level in this model, but it is significant in Model 1.

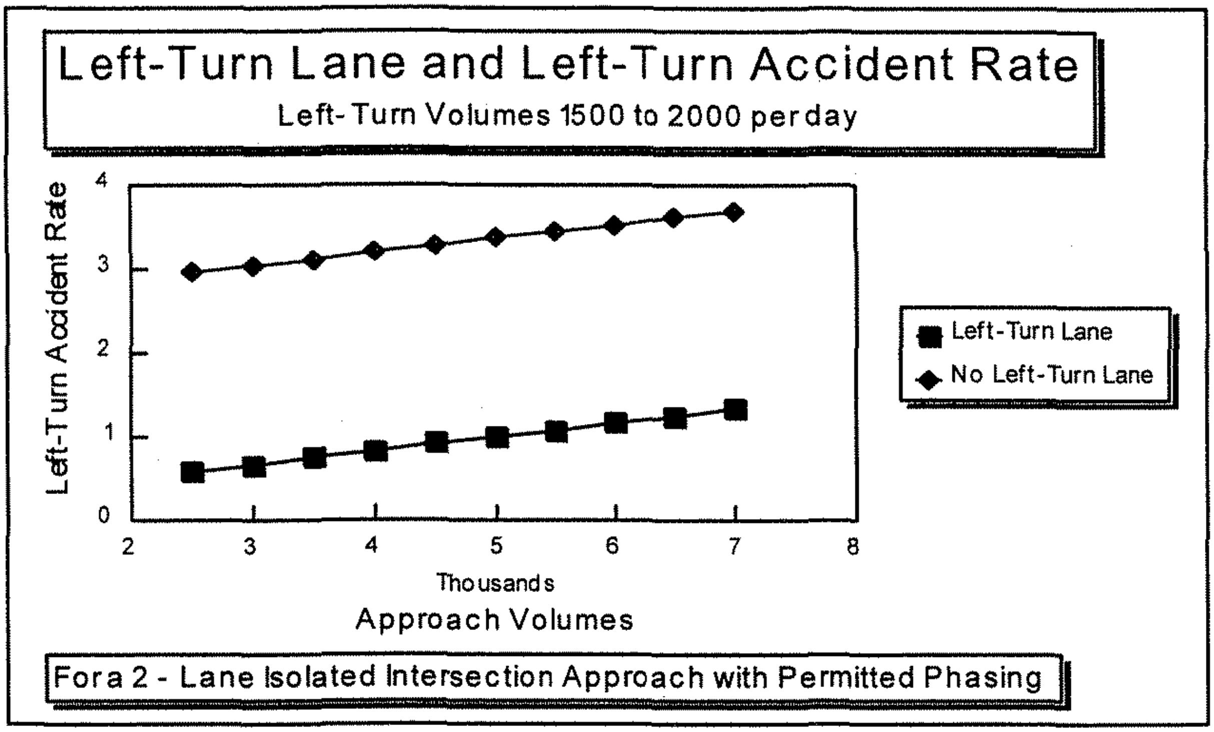


Figure 9: Effect of left-turn lane on left-turn accident rate

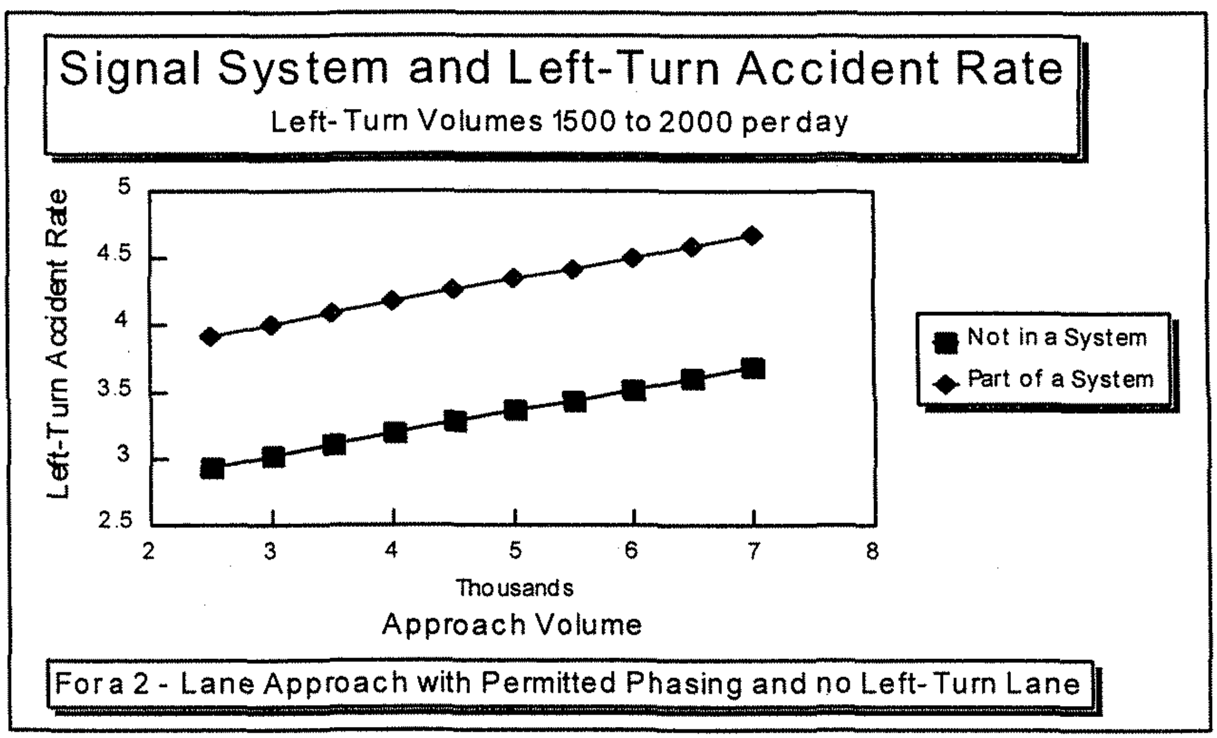


Figure 10: Effect of being in a coordinated signal system

**Approach Accident Rate Model**

A linear model was developed for approach accident rate for daily left-turn volumes between 1,500 and 2,000. The dependent variable is approach accident rate which is the number of accidents on the approach per million vehicles on the approach. The model is:

$$
\begin{aligned}
ACCRATE = \; & 2.22 + \underset{(0.6047)}{0.23}\ MEDIAN + \underset{(0.9222)}{0.03}\ LANES - \underset{(0.6111)}{2.23}\ LLANES + \underset{(0.9211)}{0.04}\ LWIDTH - \\
& \underset{(0.4863)}{0.024}\ PERMIT - \underset{(0.5066)}{0.31}\ PROTECT + \underset{(0.3958)}{0.000044}\ TOTVOL
\end{aligned}
$$

(Model 4)

None of the parameter estimates for this model are statistically significant at the 10 percent level. The $R^2$ for this model is 0.402. Some of the parameter estimates in this model are not consistent with the parameter estimates in Model 2. The parameter estimates for LANES, PERMIT and TOTVOL are of opposite sign when compared to Model 2. This may be explained by the fact that these parameter estimates are significant in Model 2.

**Other Regression Results**

All of the other regression models estimated for the remaining traffic volumes are shown in Table 1. The remaining regressions provided models with parameter estimates lacking statistical significance. Because of the lack of statistically significant parameter estimates, it is impossible to interpret their meaning.

**Table 1: Regression Equation Results**

**Volume Interval 0 to 500**

ACCRATE = 1.62 - 0.19 MEDIAN - 0.25 LANES + 0.33 LLANES - 0.03 LWIDTH - 0.45 PERMIT + 0.25 PROTECT - 0.000029 TOTVOL

$R^2$ = 0.263

(Model 5)

LACCRATE = 1.79 - 0.25 SYSTEM + 2.46 LLANES - 0.27 LWIDTH + 0.86 PERMIT + 3.54 PROTECT + 0.000027 TOTVOL

$R^2$ = 0.234

(Model 6)

**Volume Interval 1,000 to 1,500**

ACCRATE = 0.49 + 0.58 MEDIAN + 0.11 LANES - 0.24 LLANES - 0.04 LWIDTH + 0.13 PERMIT + 0.60 PROTECT - 0.000043 TOTVOL

$R^2$ = 0.244

(Model 7)

LACCRATE = 0.07 + 1.43 SYSTEM - 0.64 LLANES + 0.01 LWIDTH + 0.55 PERMIT + 0.97 PROTECT - 0.000037 TOTVOL

$R^2$ = 0.137

(Model 8)

**Volume Interval 2,000 or greater**

ACCRATE = 0.99 + 0.15 MEDIAN + 0.27 LANES - 0.37 LLANES - 0.01 LWIDTH + 0.22 PERMIT - 0.08 PROTECT - 0.000034 TOTVOL

$R^2$ = 0.39

(Model 9)

LACCRATE = 0.98 - 0.003 SYSTEM + 0.06 LLANES - 0.05 LWIDTH + 0.40PERMIT + 1.80 PROTECT - 0.000095 TOTVOL

$R^2$ = 0.15

(Model 10)

## MODEL INTERPRETATION

It is unfortunate that the majority of the statistical analysis resulted in models with statistically insignificant parameter estimates. However, this .was not necessarily unexpected. Variation in intersection accident rates is caused by intersection attributes not accounted for in the database. For example, elderly drivers are known to be more involved in left-turn accidents than other drivers. A high proportion of elderly drivers using an intersection could potentially increase the accident rate more than the other factors included in the intersection database. Such factors resulted in the inability to develop good models for all volume ranges.

The fact that reasonably good models were developed for some volume ranges illustrates the validity of the approach. The acceptable models are consistent with observations taken from the literature and from the researchers' engineering judgment. Therefore, in the future, with additional research, and better data it is reasonable to expect that acceptable models could be developed over all volume ranges. Recommended improvements in data collection are listed in Chapter 5.

The next section illustrates the use of models developed. Given that acceptable models were developed and the assumption that acceptable models could be developed over all ranges of volumes, the next section explores use of the acceptable models.

### Applications

The primary purpose for the development of the models is to provide traffic engineers with a tool to make trade-offs between the costs of intersection improvements, intersection delay, and potential accident costs. The acceptable models developed in the prior section allow the traffic engineer to simultaneously consider delay, safety, and construction cost when estimating the costs and benefits of various design alternatives.

The accident implications of a change in intersection design can be estimated using a model to estimate the accident rate with existing traffic conditions and a new intersection geometry and/or signal phasing. For example, consider an approach at an intersection that has permitted phasing. If the opposing traffic volumes are high, then it may be difficult for left turning traffic to find suitable gaps for making left-turns. As a result, left-turning vehicles may suffer long delays and left-turn accident rates may be high. At such an approach a change in the left-turn phasing could be a solution to reduce left-turn delay and accidents. The phasing may be changed to protected/permitted and a left-turn lane added. The change in the number of accidents can be estimated using the model. The economic benefits and costs of reducing the accident rate, construction cost of intersection modifications, cost of modifying signalization, and the delay benefits and costs can be compared to select the most cost effective alternative.

**Example Problem Illustrating the Use of the Research**

The results of the research described in the previous sections have been incorporated into an example problem to illustrate their use. This example involves a signalized intersection in Iowa. The intersection has experienced a high number of accidents involving left-turning vehicles.

The intersection has four approaches with two lanes on each approach as shown in Figure 11. It has a two phase operation and an 80 second cycle length is assumed for the analysis. The

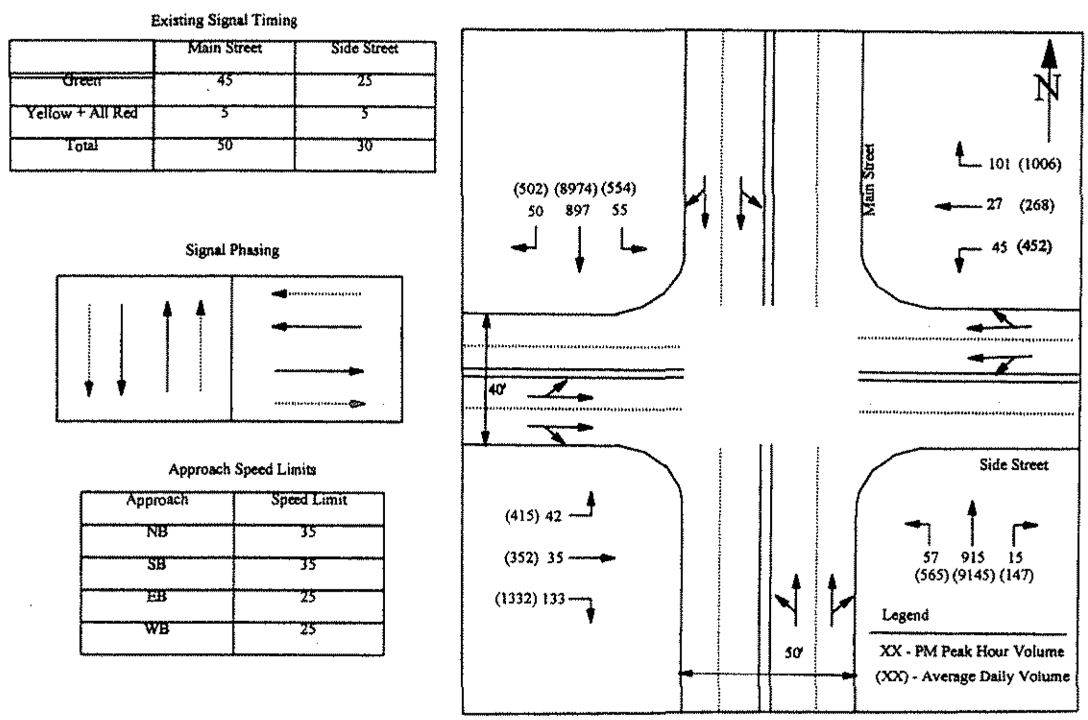


Figure 11. Intersection Characteristics

turning movement counts are shown for the evening peak hour and an average weekday. The approach speed limits are 35 miles per hour on the Main Street and 25 miles per hour on the Side Street.

The accident history for this intersection was obtained from the Iowa Department of Transportation Accident Location and Analysis System (ALAS). A summary of accidents are shown in Table 2 for the northbound and southbound approaches. There was a total of 15 accidents on the northbound approach and 19 on the southbound approach during the three year period. The majority of these accidents involved at least one left turning vehicle.

Table 2: Accident Summary for Northbound and Southbound Approaches for 1989 through 1991

| | Accident Type | 1989 | 1990 | 1991 | Total |
|---|---|---|---|---|---|
| N | Angle | 2 | | | 2 |
| O | Left Turn | 4 | | 4 | 8 |
| R | Rear End | 2 | 1 | 2 | 5 |
| T | Head On | | | | 0 |
| H | Sideswipe | | | | 0 |
| B | Fixed Object | | | | 0 |
| O | Pedestrian | | | | 0 |
| U | Bicycle | | | | 0 |
| N | Other | | | | 0 |
| D | Total | 8 | 1 | 6 | 15 |
| S | Angle | | | 2 | 2 |
| O | Left Turn | 6 | 3 | 6 | 15 |
| U | Rear End | | 1 | 1 | 2 |
| T | Head On | | | | 0 |
| H | Sideswipe | | | | 0 |
| B | Fixed Object | | | | 0 |
| O | Pedestrian | | | | 0 |
| U | Bicycle | | | | 0 |
| N | Other | | | | 0 |
| D | Total | 6 | 4 | 9 | 19 |

The left-turn accident rate (LACCRATE) was calculated for the northbound and southbound approaches using Model 1 and the results are presented in Table 3. Model 1 was developed with data from intersections with left turn volumes between 500 and 1,000. The example intersection also experiences left turn volumes in this interval. As shown in Table 3, under the column "existing conditions," are the values of the variables in Model 1. For example, in the northbound direction, the intersection is part of a signal system, it has permitted left-turn

Table 3: Predicted Left-Turn Accident Rate for the Northbound and Southbound Approaches

| | | | Alternatives | | | |
|---|---|---|---|---|---|---|
| | Variables | Existing Conditions | Protected Phasing w/o LT Lane | Permitted Phasing with LT Lane | Protect/Perm Phasing with LT Lane | Protected Phasing with LT Lane |
| NORTH BOUND | SYSTEM | 1 | 1 | 1 | 1 | 1 |
| | LLANES | 0 | 0 | 1 | 1 | 1 |
| | LWIDTH | 0 | 0 | 12 | 12 | 12 |
| | PERMIT | 1 | 0 | 1 | 1 | 0 |
| | PROTECT | 0 | 1 | 0 | 1 | 1 |
| | TOTVOL | 9857 | 9857 | 9857 | 9857 | 9857 |
| | LACCRATE | 7.93 | 3.9 | 7.49 | 5.2 | 3.46 |
| SOUTH BOUND | SYSTEM | 1 | 1 | 1 | 1 | 1 |
| | LLANES | 0 | 0 | 1 | 1 | 1 |
| | LWIDTH | 0 | 0 | 12 | 12 | 12 |
| | PERMIT | 1 | 0 | 1 | 1 | 0 |
| | PROTECT | 0 | 1 | 0 | 1 | 1 |
| | TOTVOL | 10030 | 10030 | 10030 | 10030 | 10030 |
| | LACCRATE | 8.02 | 3.98 | 7.57 | 5.28 | 3.54 |

phasing, and the total approach volume is 9,857 vehicles per day. When these values are input to Model 1, the estimated left-turn accident rate is 7.93 accidents per million left turning vehicles. In the southbound direction, the model estimates an accident rate of 8.02.

Model 1 is also used to develop accident rate estimates for four alternative left-turn treatments. The estimated accident rate for each alternative treatment is shown in Table 3.

**Left-Turn Treatment Alternatives**

Four alternatives were selected for evaluation. Each alternative, based on standard traffic engineering practice, was selected because it could reduce the probability of left-turn accidents. The reduced likelihood of left-turn accidents reduces future traffic accidents costs and, therefore, provides a quantifiable safety benefit. On the other hand, each improvement implies increased construction costs and may increase intersection delay. For each of the four alternatives, all of these costs were evaluated in a single benefit-cost ratio and thus allowing the traffic engineer to select the most cost effective alternative. The four alternative left-turn treatment improvements include:

1. Changing the northbound and southbound approaches from permitted phasing to protected phasing without adding a left turn lane (split phasing);
2. Adding a left turn lane to both approaches with the existing permitted left-turn phasing;
3. Adding a left-turn lane to both approaches with protected/permitted phasing, and;
4. Adding a left-turn lane to both approaches with protected phasing.

The results of the left-turn accident rates are lowest when there is protected left-turn phasing with a left-turn lane for both northbound and southbound approaches. Thus, based on this analysis, protected phasing with the added left turn lane would be the best alternative for reducing accidents.

**Benefit/Cost Analysis**

A Benefit/Cost Analysis was conducted to determine the overall effects of the alternatives. The analysis includes the potential for the alternatives to reduce accidents, the change in the approach delay associated with each alternative, and the construction cost of each alternative. First, the predicted number of accidents was calculated for all of the alternatives using Model 1 to determine how the proposed changes would effect the accident potential at the intersection (see Table 4). The largest predicted reductions in accidents would be produced by the two alternatives that involve protected phasing.

The approach delay was calculated using the Highway Capacity Manual software to compare the effect of each alternative (see Table 5). The cycle length was assumed to be the same for each of the alternatives. The only alternative reducing delay uses permitted phasing with a left turn lane.

Construction costs were estimated for each of the alternatives (see Table 6). The lowest cost alternative is to add protected phasing without a left turn lane. All other alternatives were assumed to cost the same amount.

Table 4: Predicted Accident Reduction Per Million Left-Turning Vehicles

| | | Alternative | LACCRATE | Predicted Number of Accidents | Predicted Accident Reduction | Percentage Reduction |
|---|---|---|---|---|---|---|
| N | B | Existing Conditions | 7.93 | 4.91 | 0 | 0 |
| O | O | Protected Phasing w/o LT Lane | 3.9 | 2.41 | 2.5 | 50.85 |
| R | U | Add LT Lane with Permit. Phasing | 7.49 | 4.64 | 0.27 | 5.56 |
| T | N | Protect/Perm Phasing with LT Lane | 5.2 | 3.22 | 1.69 | 34.48 |
| H | D | Protected Phasing with LT Lane | 3.46 | 2.14 | 2.77 | 56.42 |
| | | | | | | |
| S | B | Existing Conditions | 8.02 | 4.86 | 0 | 0 |
| O | O | Protected Phasing w/o LT Lane | 3.98 | 2.42 | 2.45 | 50.33 |
| U | U | Add LT Lane with Permit. Phasing | 7.57 | 4.59 | 0.27 | 5.51 |
| T | N | Protect/Perm Phasing with LT Lane | 5.28 | 3.2 | 1.66 | 34.12 |
| H | D | Protected Phasing with LT Lane | 3.54 | 2.15 | 2.72 | 55.84 |

Table 5: Approach Delay for Alternatives

| | Northbound Approach | | Southbound Approach | |
|---|---|---|---|---|
| Alternative | Predicted Delay (sec/veh) | Predicted Change (sec/veh) | Predicted Delay (sec/veh) | Predicted Change (sec/veh) |
| Existing Conditions | 8.3 | 0 | 8.3 | 0 |
| Protected Phasing w/o LT Lane | 65.6 | -57.3 | 74.5 | -66.2 |
| Add LT Lane with Permit. Phasing | 5.2 | 3.1 | 5.3 | 3 |
| Protect/Perm Phasing with LT Lane | 12.9 | -4.6 | 13.1 | -4.8 |
| Protected Phasing with LT Lane | 13.5 | -5.2 | 13.7 | -5.4 |

Table 6: Estimated Construction Cost for Each of the Alternatives

| Alternative | Construction Cost |
|---|---|
| Protected Phasing w/o LT Lane | $540 |
| Add LT Lane with Permit. Phasing | $114,431 |
| Protect/Perm Phasing with LT Lane | $114,431 |
| Protected Phasing with LT Lane | $114,431 |

Finally, a Benefit/Cost ratio analysis was conducted incorporating all factors into the analysis. The Benefit/Cost ratio was calculated under three scenarios to show the sensitivity of the solution to the assumptions and to illustrate the use of the model in making trade-offs between a reduced potential for accidents, delay costs, and construction costs. In all scenarios an interest rate of eight percent was used for discounting future costs and benefits. The project was assumed to have a life of 20 years.

The accidents that occurred at this particular intersection in the past were property damage only accidents. However, an average accident value is used for the cost of future accidents. This is an average accident cost of $11,500. Eleven thousand five hundred dollars was the average cost of all accidents throughout Iowa for 1991 (1). It would be preferable to have an average accident for highway a facility with similar characteristics (i.e., high speed signalized intersections). However, such data are not available. The reason for the use of average accident costs can best be envisioned by supposing, through random misfortune, one of the accidents resulted in a fatality. The State of Iowa estimates the average cost of a fatal accident is $500,000. If it is then assumed accidents in the future would result in fatalities (very high cost accidents), almost any measure to improve the safety of the intersection would be justified. Instead an average accident cost is used so that very high cost accidents, and similarly very low cost accidents, do not unduly bias the left-turn treatment utilized. Because the extent of damage done by an accident is random, the average cost of accidents over a large number of incidents at similar facilities is a better predictor of future costs than a small sample at one location.

In the first scenario, the value for delaying the driver and vehicle is assumed to have a cost of $11.65 per hour. This value is based on the value of time used in a study of capacity improvements to the U.S. Highway 20 corridor and assumes the driver is on a business trip and there are no passengers in the automobile (2). Clearly, the value of time can vary depending on the amount of time saved (individuals value more highly a minute saved from a ten minute delay than they would a minute saved from a two minute delay), and the type of trip being made.

Shown in Table 7A is the northbound approach and in Table 7B the southbound approach delay impacts of each alternative compared to the existing condition. Changing the left-turn phasing to permitted an adding a left-turn lane is the only alternative that reduces delay costs. In Table 7C are the results of discounting future costs and future benefits (reduced delay and/or reduced accidents). Only the second alternative provides positive benefits (combined delay and accident costs savings) and, therefore, a benefit to cost ratio is calculated only for alternative two. The others provide estimates of negative benefits. Based on this calculation alternative two is the most cost effective alternative and should be selected.

Table 8A, 8B, and 8C illustrate the second scenario. The second scenario assumes a very low value for delay time, $3.25. This value is selected because it illustrates the importance of the value of a motorists time and the consideration of delay. When the value of delay time is high, the alternative that most greatly reduces delay dominates the analysis (alternative two). When the value of delay is low, the alternative creating the most safety benefits dominates. As a result, alternative four is the preferred alternative (see Table 8C).

Table 7A: Northbound Approach Annual Delay Cost Savings;
Assuming a Delay Cost of $11.65 per Hour
and an Accident Cost of $11,500 per Accident

| | | Northbound Approach | | |
|---|---|---|---|---|
| Alternative | Predicted Delay (Sec/Veh) | Predicted Change (Sec/Veh) | Annual Delay (Hours) | Annual Delay Savings |
| Existing Condition | 8.3 | 0 | 0 | $0.00 |
| Protected Phasing w/o LT Lane | 65.6 | -57.3 | -57,265 | -$667,137 |
| Add LT Lane With Permitted Phasing | 5.2 | 3.1 | 3,098 | $36,092 |
| Protected/Permitted Phasing with LT Lane | 12.9 | -4.6 | -4,597 | -$53,557 |
| Protected Phasing With LT Lane | 13.5 | -5.2 | -5,197 | -$60,543 |

Table 7B: Southbound Approach Annual Delay Cost Savings;
Assuming a Delay Cost of $11.65 per Hour
and an Accident Cost of $11,500 per Accident

| | | Southbound Approach | | |
|---|---|---|---|---|
| Alternative | Predicted Delay (Sec/Veh) | Predicted Change (Sec/Veh) | Annual Delay (Hours) | Annual Delay Savings |
| Existing Condition | 8.3 | 0 | 0 | $0.00 |
| Protected Phasing w/o LT Lane | 74.5 | -66.2 | -67,321 | -$784,287 |
| Add LT Lane With Permitted Phasing | 5.3 | 3 | 3,051 | $35,541 |
| Protected/Permitted Phasing with LT Lane | 13.1 | -4.8 | -4,881 | -$56,866 |
| Protected Phasing With LT Lane | 13.7 | -5.4 | -5,491 | -$63,975 |

Table 7C: Benefit to Cost Analysis Assuming a Delay Cost of $11.65 per Hour and an Accident Cost of $11,500 per Accident

| Alternative | Total Annual Delay Savings | Total Annual Accident Savings | Present Worth of Benefits | Present Worth of Costs | Benefit to Cost Ratio |
|---|---|---|---|---|---|
| Existing Condition | $0 | $0 | $0 | $0 | 0 |
| Protected Phasing w/o LT Lane | -$1,451,425 | $56,925 | -$63,815,124 | $540 | N.A. |
| Add LT Lane with Permitted Phasing | $71,635 | $6,210 | $3,562,329 | $114,431 | 31.13 |
| Protected/Permitted Phasing with LT Lane | -$110,424 | $39,195 | -$3,259,585 | $114,431 | N.A. |
| Protected Phasing with LT Lane | -$124,518 | $63,135 | -$2,809,016 | $114,431 | N.A. |

Table 8A: Northbound Approach Annual Delay Cost Savings; Assuming a Delay Cost of $3.25 per Hour and an Accident Cost of $11,500 per Accident

| | | Northbound Approach | | |
|---|---|---|---|---|
| Alternative | Predicted Delay (Sec/Veh) | Predicted Change (Sec/Veh) | Annual Delay (Hours) | Annual Delay Savings |
| Existing Condition | 8.3 | 0 | 0 | $0.00 |
| Protected Phasing w/o LT Lane | 65.6 | -57.3 | -57,265 | -$186,111 |
| Add LT Lane With Permitted Phasing | 5.2 | 3.1 | 3,098 | $10,068 |
| Protected/Permitted Phasing with LT Lane | 12.9 | -4.6 | -4,597 | -$14,940 |
| | 13.5 | -5.2 | -5,197 | -$16,889 |

Table 8B: Southbound Approach Annual Delay Cost Savings ; Assuming a Delay Cost of $3.25 per Hour and an Accident Cost of $11,500 per Accident

| Alternative | Predicted Delay (Sec/Veh) | Southbound Approach<br>Predicted Change (Sec/Veh) | Annual Delay (Hours) | Annual Delay Savings |
|---|---|---|---|---|
| Existing Condition | 8.3 | 0 | 0 | $0.00 |
| Protected Phasing w/o LT Lane | 74.5 | -66.2 | -67,321 | -$404,905 |
| Add LT Lane With Permitted Phasing | 5.3 | 3 | 3,051 | $19,983 |
| Protected/Permitted Phasing with LT Lane | 13.1 | -4.8 | -4,881 | -$30,805 |
| Protected Phasing With LT Lane | 13.7 | -5.4 | -5,491 | -$34,737 |

Table 8C: Benefit to Cost Analysis Assuming a Delay Cost of $3.25 per Hour and an Accident Cost of $11,500 per Accident

| Alternative | Total Annual Delay Savings | Total Annual Accident Savings | Present Worth of Benefits | Present Worth of Costs | Benefit to Cost Ratio |
|---|---|---|---|---|---|
| Existing Condition | $0 | $0 | $0 | $0 | 0 |
| Protected Phasing w/o LT Lane | -$404,904 | $56,925 | -$15,924 | $540 | N.A. |
| Add LT Lane with Permitted Phasing | $191,984 | $6,210 | $1,198,687 | $114,431 | 10.48 |
| Protected/Permitted Phasing with LT Lane | -$30,805 | $39,195 | $383,943 | $114,431 | 3.36 |
| Protected Phasing with LT Lane | -$34,737 | $63,135 | $1,299,557 | $114,431 | 11.36 |

To illustrate the sensitivity of the solution to the cost assigned to future accidents, the analysis conducted in scenario three uses an average accident value of $40,000 and a time value of delay of $11.65 per hour. The new analysis is shown in Tables 9A, 9B, and 9C. By increasing the cost of accidents, the benefits of reducing accidents are increased. This increases the attractiveness of alternatives which most greatly reduce the potential of accidents. Therefore, alternative four is the most attractive alternative.

Table 9A: Northbound Approach Annual Delay Cost Savings;
Assuming a Delay Cost of $11.65 per Hour
and an Accident Cost of $40,000 per Accident

| | Northbound Approach | | | |
|---|---|---|---|---|
| Alternatives | Predicted Delay (Sec/Veh) | Predicted Change (Sec/Veh) | Annual Delay (Hours) | Annual Delay Savings |
| Existing Condition | 8.3 | 0 | 0 | $0.00 |
| Protected Phasing w/o LT Lane | 65.6 | -57.3 | -57,265 | -$667,137 |
| Add LT Lane With Permitted Phasing | 5.2 | 3.1 | 3,098 | $36,092 |
| Protected/Permitted Phasing with LT Lane | 12.9 | -4.6 | -4,597 | -$53,557 |
| Protected Phasing With LT Lane | 13.5 | -5.2 | -5,197 | -$60,543 |

Table 9B: Southbound Approach Annual Delay Cost Savings:
Assuming a Delay Cost of $11.65 per Hour
and an Accident Cost of $40,000 per Accident

| | Southbound Approach | | | |
|---|---|---|---|---|
| Alternative | Predicted Delay (Sec/Veh) | Predicted Change (Sec/Veh) | Annual Delay (Hours) | Annual Delay Savings |
| Existing Condition | 8.3 | 0 | 0 | $0.00 |
| Protected Phasing w/o LT Lane | 74.5 | -66.2 | -67,321 | -$784,287 |
| Add LT Lane With Permitted Phasing | 5.3 | 3 | 3,051 | $35,541 |
| Protected/Permitted Phasing with LT Lane | 13.1 | -4.8 | -4,881 | -$56,866 |
| Protected Phasing With LT Lane | 13.7 | -5.4 | -5,491 | -$63,975 |

Table 9C: Benefit to Cost Analysis Assuming a Delay Cost of $11.65 per Hour and an Accident Cost of $40,000 per Accident

| Alternative | Total Annual Delay Savings | Total Annual Accident Savings | Present Worth of Benefits | Present Worth of Costs | Benefit to Cost Ratio |
|---|---|---|---|---|---|
| Existing Condition | $0 | $0 | $0 | $0 | 0 |
| Protected Phasing w/o LT Lane | -$1,451,425 | $198,000 | -$57,359,250 | $540 | N.A. |
| Add LT Lane with Permitted Phasing | $71,635 | $21,600 | $4,266,606 | $114,431 | 37.29 |
| Protected/Permitted Phasing with LT Lane | -$110,424 | $134,000 | $1,078,881 | $114,431 | 9.43 |
| Protected Phasing with LT Lane | -$124,518 | $219,600 | $4,351,135 | $114,431 | 38.02 |

1 Memorandum from J. Michael Laski, Director, Governor's Traffic Safety Bureau, to Paul H. Wieck II, Commission Department of Public Safety, March 30, 1993. Subject: Cost of Traffic Fatalities in Iowa.

2 Wilbur Smith Associates, *Guide to the Economic Evaluation of Highway Projects*, Prepared for the Iowa Department of Transportation, Ames, Iowa, 1993.

# CHAPTER 5

# CONCLUSIONS

Left-turn accidents are over represented by a factor of three in the total accident population. Because left-turn maneuvers are more hazardous than other traffic movements, the design of the most effective left-turn treatment is crucial. The purpose of this research is to develop statistical models to allow the engineer to make trade-offs during the design and evaluation of alternatives. Traditionally, there have been excellent tools for the analysis of capacity and delay considerations while designing intersections. However, there have not been acceptable methods for including predicted accident costs in the economic analysis of alternative left-turn treatments. In the past, engineers have used to engineering judgment or locally developed warrants for left-turn treatments.

In this research, a data base was generated for the statistical estimation of relationships between accident experience, intersection traffic characteristics, and left-turn treatments. Much of the statistical analysis resulted in models with poor statistical properties. However, a few of the models developed provided acceptable statistical results and an example is provided of the models use and the sensitivity of the model to changes in input parameters.

The data were divided into data sets based on the left-turn volumes; 0 to 500 left-turning vehicles per day, 500 to 1,000, 1,000 to 1,500, 1,500 to 2,000, and 2,000 or greater. Each data set contained information regarding accidents, intersection geometry, and traffic volumes from intersections within the left-turn volume interval. Satisfactory models were developed only for the 500 to 1,000 vehicle per day interval and reasonable models for the 1,500 to 2,000. The results are interpreted to mean that there are relationships between left-turn accident rates, traffic characteristics, and left-turn treatments. The models with acceptable statistical results seem reasonable and logical. Further, more investigation is recommend to develop higher fidelity models. However, in future research, better data collection procedures are recommended.

The specific recommendations include:

1. It is recommended that traffic accident and traffic volumes cover the peak hour rather then the entire day. Typically, intersections are designed to satisfy peak hour traffic volumes.

2. City traffic engineers were asked to provide intersection geometric data and traffic volume data for current conditions. The questionnaire asked engineers to provide data only for intersections that had not been reconstructed or had significant modifications over the last five years. However, current traffic volumes and signal phasing may not necessarily be indicative of conditions for every year in the last five years. It is recommended that data collected for intersections should include a time series of traffic data and signal operation for every year in the data base.

3. The accident data were gathered from the state level accident reporting system. Although the state accident data base is the most comprehensive reporting system available in Iowa, not all jurisdictions are equally judicious in their reporting of accidents to the Iowa Department of Transportation. Further, some jurisdictions keep more up-to-date records using their own files. It is recommended that accident record keeping practices of each jurisdiction within the study be examined for consistency.

The example problem in Chapter 4 illustrates the use of one of the models in the selection of an alternative design of an intersection. Model 1 may be used in similar situations, in the design of intersections with left-turn volumes of 500 to 1,000 vehicles per day, with reasonable confidence in the results. It is even reasonable to use the model for design of intersections with left-turn volumes outside of the 500 to 1,000 vehicles per day range to provide an initial estimate of the implications of various left-turn treatment. But, more work is required to develop operational models for common intersection evaluation purposes. However, the most important contribution of the work reported here is to illustrate that such models may be developed.

## APPENDIX A

## QUESTIONNAIRE

 *PLEASE ANSWER ALL THAT APPLIES*

Name of **north-south street**:

Name of **east-west street**:

**1. Signal head type & Position:**

| | yes | no | not sure |
|---|---|---|---|
| Mast-arm overhead | ◯ | ◯ | ◯ |
| Side mounted | ◯ | ◯ | ◯ |
| Span wire overhead | ◯ | ◯ | ◯ |
| Monotube | ◯ | ◯ | ◯ |

*Other / comment*

**2. Signal lens visor/visibility:** *✓ the type you have!*

| Type → Approach ↓ | tunnel | cut-off | programmable visibility | other please explain |
|---|---|---|---|---|
| North thru | | | | |
| North left | | | | |
| South thru | | | | |
| South left | | | | |
| East thru | | | | |
| East left | | | | |
| West thru | | | | |
| West left | | | | |

*Other / comment*

**3. Back plates?** *✓ if you have it!*

| Approach ↓ | yes | no | not sure |
|---|---|---|---|
| North thru | ◯ | ◯ | ◯ |
| North left | ◯ | ◯ | ◯ |
| South thru | ◯ | ◯ | ◯ |
| South left | ◯ | ◯ | ◯ |
| East thru | ◯ | ◯ | ◯ |
| East left | ◯ | ◯ | ◯ |
| West thru | ◯ | ◯ | ◯ |
| West left | ◯ | ◯ | ◯ |

*Other / comment*

**About information on this page**

If you feel someone from Iowa Transportation Center needs to visit with you or visit the location please check the box:

☐ **contact me.**

Name of **north-south street:**

Name of **east-west street:**

**4. Signal lens size?** ✓ ***the appropriate size!***

| Approach ↓ | 8 inches | 12 inches | not sure |
|---|---|---|---|
| North thru | ○ | ○ | ○ |
| North left | ○ | ○ | ○ |
| South thru | ○ | ○ | ○ |
| South left | ○ | ○ | ○ |
| East thru | ○ | ○ | ○ |
| East left | ○ | ○ | ○ |
| South thru | ○ | ○ | ○ |
| South left | ○ | ○ | ○ |

*Other / comment*

**5. Is there a raised median/island?**

| | **yes** | **no** | **not sure** |
|---|---|---|---|
| North leg | ○ | ○ | ○ |
| South leg | ○ | ○ | ○ |
| East leg | ○ | ○ | ○ |
| West leg | ○ | ○ | ○ |

*Other / comments:*

**6. Is there a painted median/island?**

| | | | |
|---|---|---|---|
| North leg | ○ | ○ | ○ |
| South leg | ○ | ○ | ○ |
| East leg | ○ | ○ | ○ |
| West leg | ○ | ○ | ○ |

*Other / comments:*

**About information on this page**
If you feel someone from Iowa Transportation Center needs to visit with you or visit the location please check the box:
☐ **contact me.**

Name of **north-south street:**

Name of **east-west street:**

| | yes | no | not sure |
|---|---|---|---|
| 7. **System information?** | | | |
| Isolated? | ◯ | ◯ | ◯ |
| Coordinated | ◯ | ◯ | ◯ |

*Other/comments:*

**8. If coordinated:**
**What is the means of coordination?**

| | yes | no | not sure |
|---|---|---|---|
| Hard wire | ◯ | ◯ | ◯ |
| Radial | ◯ | ◯ | ◯ |
| External time clock | ◯ | ◯ | ◯ |
| Internal time clock | ◯ | ◯ | ◯ |
| None | ◯ | ◯ | ◯ |

*Other/Comment*

**9. If coordinated:**
**What is the control system/supervision type?**

| | yes | no | not sure |
|---|---|---|---|
| Closed-loop | ◯ | ◯ | ◯ |
| Central | ◯ | ◯ | ◯ |
| Master supervision only | ◯ | ◯ | ◯ |
| No supervision | ◯ | ◯ | ◯ |

**10. If coordinated:**
**Does your timing plan change by:**

| | yes | no | not sure |
|---|---|---|---|
| Time of day? | ◯ | ◯ | ◯ |
| Time of year? | ◯ | ◯ | ◯ |
| Day of week? | ◯ | ◯ | ◯ |
| Special events? | ◯ | ◯ | ◯ |
| Traffic responsive algorithm? | ◯ | ◯ | ◯ |

*Other/comments:*

**11. Type of control?**

| | yes | no | not sure |
|---|---|---|---|
| Actuated | ◯ | ◯ | ◯ |
| Semi-actuated | ◯ | ◯ | ◯ |
| Pretimed | ◯ | ◯ | ◯ |
| Preemption | ◯ | ◯ | ◯ |

*Other/Comment*

**About information on this page**
If you feel someone from Iowa Transportation Center needs to visit with you or visit the location please check the box:
☐ **contact me.**

Name of **north-south street**:

Name of **east-west street**:

**12. Type of controller?**

| | | | |
|---|---|---|---|
| Electro-mechanical | ○ | ○ | ○ |
| Pre-NEMA solid state | ○ | ○ | ○ |
| NEMA | ○ | ○ | ○ |
| Type 170 | ○ | ○ | ○ |

*Other / comment*

Please enclose all the timing, phasing, and other signal information that you might have *on computer disk or paper!*

**About information on this page**

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| Intersection nimber or ID | page 5 of 12 | *PLEASE ANSWER ALL THAT APPLIES* |
|---|---|---|

Name of **north-south street:**

Name of **east-west street:**

*13. (GOOD LUCK):*

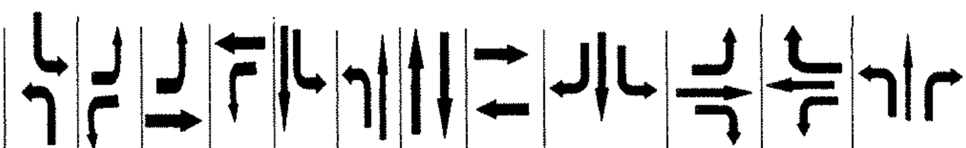
**Pretimed** Check the movement in the signal phase sequence.

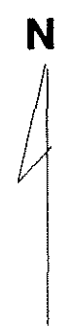
**Actuated:** If known, check the predominant movement in the signal phase sequence and note the time period for it. Use additional sheets for multiple time periods.

TIME PERIOD:______________________

**Time:** Please write the corresponding green, and yellow + all red times at the bottom of the table.

| | yes | no | may be so! |
|---|---|---|---|
| Actuated? | ○ | ○ | ○ |
| Pretimed? | ○ | ○ | ○ |
| Semi-actuated | ○ | ○ | ○ |
| Times shown below are in seconds | ○ | ○ | ○ |
| Times shown below are in percents | ○ | ○ | ○ |






| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1st phase | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| 2nd phase | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| 3rd phase | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| 4th phase | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| 5th phase | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| 6th phase | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| 7th phase | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| 8th phase | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| Pretimed Green: | | | | | | | | | | | | |
| Actuated Avg. Green | | | | | | | | | | | | |
| Yel. + all red | | | | | | | | | | | | |
| Left turn Permitted? | | | | | | | ○ | ○ | | | | |

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Intersection nimber or ID  *PLEASE ANSWER ALL THAT APPLIES*

Name of **north-south street:**

Name of **east-west street:**

**14 Number of timing plans:**

| | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| How many timing plans are you running? | ◯ | ◯ | ◯ | ◯ | ◯ |
| Corresponding cycle length | ____ | ____ | ____ | ____ | ____ |

*Other/comment:*

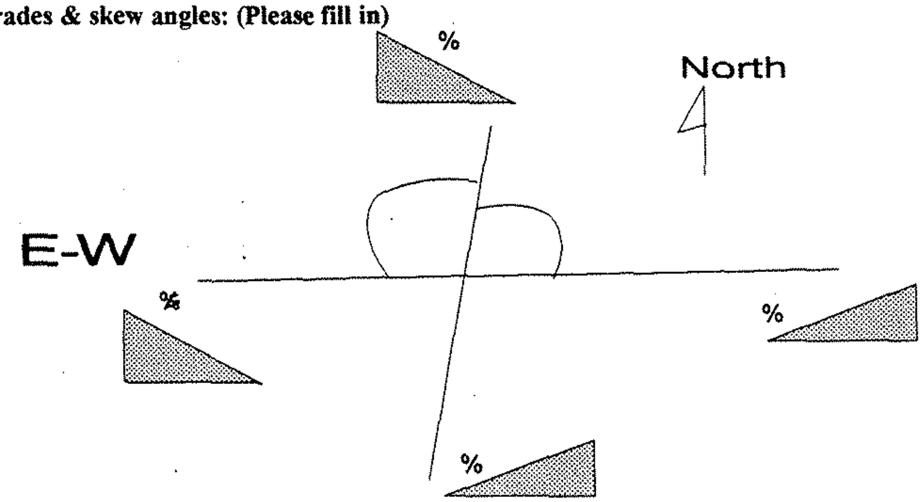
15. Number of lanes, lane widths and storage capacity

| **Lane use →** *Approach ↓* | **Right only** | **Right and thru.** | **Thru only** | **Thru and left** | **Left only** | **Right and left and thru** |
|---|---|---|---|---|---|---|
| ***N. bound*** *(No. of lanes)* | | | | | | |
| ***S. bound*** *(No. of lanes* | | | | | | |
| ***E. bound*** *(No. of lanes* | | | | | | |
| ***W. bound*** *(No. of lanes* | | | | | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| ***Aerage Lane Width (ft)*** | | | | | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| ***Storage Capacity, If Applicable (ft)*** | | | | | | |
| ***Other / Comment*** | | | | | | |

**16. Approach grades & skew angles: (Please fill in)**




**17. How close to the intersection is on street parking permitted?**

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| Intersection nimber or ID | page 7 of 12 | *PLEASE ANSWER ALL THAT APPLIES* |
|---|---|---|

Name of **north-south street:**

Name of **east-west street:**

| 0 ft | 10 ft | 20 ft | 30 ft | 40 ft | 50 ft | 60 ft |
|---|---|---|---|---|---|---|
| ○ | ○ | ○ | ○ | ○ | ○ | ○ |

Other / comment

**18. Type of parking**

| Type of parking: | parallel | angled | none | other |
|---|---|---|---|---|
| | ○ | ○ | ○ | ______ |

**19. Posted speed limit (M.P.H.):**

| | |
|---|---|
| ***N. bound*** | |
| ***S. bound*** | |
| ***E. bound*** | |
| ***W. bound*** | |
| ***Other / comment*** | |

***IF POSSIBLE PLEASE IDENTIFY THE GEOMETRIC DETAILS OF THE INTERSECTION, SUCH AS SHOWN ON FIGURE 1, ON A ROUGH SKETCH***

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| Intersection nimber or ID | page 8 of 12 | *PLEASE ANSWER ALL THAT APPLIES* |
|---|---|---|

Name of **north-south street:**

Name of **east-west street:**

**20. Left turn movement treatment**

| type → *Approach* ↓ | permissive left turns | protected left turns | permissive/ protected | permissive / protected (protection activated only by certain length of queue.) | other |
|---|---|---|---|---|---|
| *N. bound* | | | | | |
| *S. bound* | | | | | |
| *E. bound* | | | | | |
| *W. bound* | | | | | |

*other/comment*

**21. Street (intersection) lighting**

| *Approach* ↓ | yes | no | not sure |
|---|---|---|---|
| *N. bound* | ◯ | ◯ | ◯ |
| *S. bound* | ◯ | ◯ | ◯ |
| *E. bound* | ◯ | ◯ | ◯ |
| *W. bound* | ◯ | ◯ | ◯ |

*other/comment*

**22. Lane alignment**

**Do opposing left turn lanes line up**

| *Approach* ↓ | yes | no | not sure | alignment with | N/A |
|---|---|---|---|---|---|
| *N. bound* | ◯ | ◯ | ◯ | | ◯ |
| *S. bound* | ◯ | ◯ | ◯ | | ◯ |
| *E. bound* | ◯ | ◯ | ◯ | | ◯ |
| *W. bound* | ◯ | ◯ | ◯ | | ◯ |

*other/comment*

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|---|---|---|
| Name of **north-south street**: | | |
| Name of **east-west street**: | | |

**23. Restriction/Regulation facing the approaching traffic**

| **Regulation →** ***Approach ↓*** | **no left turns** | **no right turns.** | **do not enter** | **other** |
|---|---|---|---|---|
| ***N. bound*** | | | | |
| ***S. bound*** | | | | |
| ***E. bound*** | | | | |
| ***W. bound*** | | | | |
| ***other/comment*** | | | | |

**24. Advance warning signs?**

| ***Approach ↓*** | **yes** | **no** | **not sure** | **if yes: what is it** |
|---|---|---|---|---|
| ***N. bound*** | ◯ | ◯ | ◯ | |
| ***S. bound*** | ◯ | ◯ | ◯ | |
| ***E. bound*** | ◯ | ◯ | ◯ | |
| ***W. bound*** | ◯ | ◯ | ◯ | |
| ***other/comment*** | | | | |

**25. Dilemma zone protection:**

| ***Approach ↓*** | **yes** | **no** | **not sure** | **N/A** |
|---|---|---|---|---|
| ***N. bound*** | ◯ | ◯ | ◯ | ◯ |
| ***S. bound*** | ◯ | ◯ | ◯ | ◯ |
| ***E. bound*** | ◯ | ◯ | ◯ | ◯ |
| ***W. bound*** | ◯ | ◯ | ◯ | ◯ |

***other/comment***

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Name of **north-south street**:

Name of **east-west street**:

**26.**

**Pedestrian signal information**

**✓ THE ITEM IF IT EXISTS**

| *Across*↓ | pedestrian signal head | pedestrian push button | not sure | walk time (seconds) | flashing don't walk time (seconds) | other |
|---|---|---|---|---|---|---|
| *North leg* | ◯ | ◯ | ◯ | | | |
| *South leg* | ◯ | ◯ | ◯ | | | |
| *East leg* | ◯ | ◯ | ◯ | | | |
| *West leg* | ◯ | ◯ | ◯ | | | |
| *other/comment* | | | | | | |

## 27. Changes, Changes, changes

| *Changes in* ↓ | ✓ here if yes | date of change | explain |
|---|---|---|---|
| *traffic generation (new commercial developments, closings, etc.)* | ◯ | | |
| *intersection layout or road construction* | ◯ | | |
| *signal hardware and equipment* | ◯ | | |
| *timing, phasing, etc.* | ◯ | | |
| *other/comment* | | | |

**28. Area Type: ✓ one:**

**C.B.D** ◯ **OTHER** ◯

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Name of **north-south street:**

Name of **east-west street:**

# PLEASE DO NOT FORGET TO ENCLOSE THE MOST RECENT TRAFFIC VOLUME COUNTS AND INFORMATION

**ON PAPER, DISK, OR OTHERWISE!**

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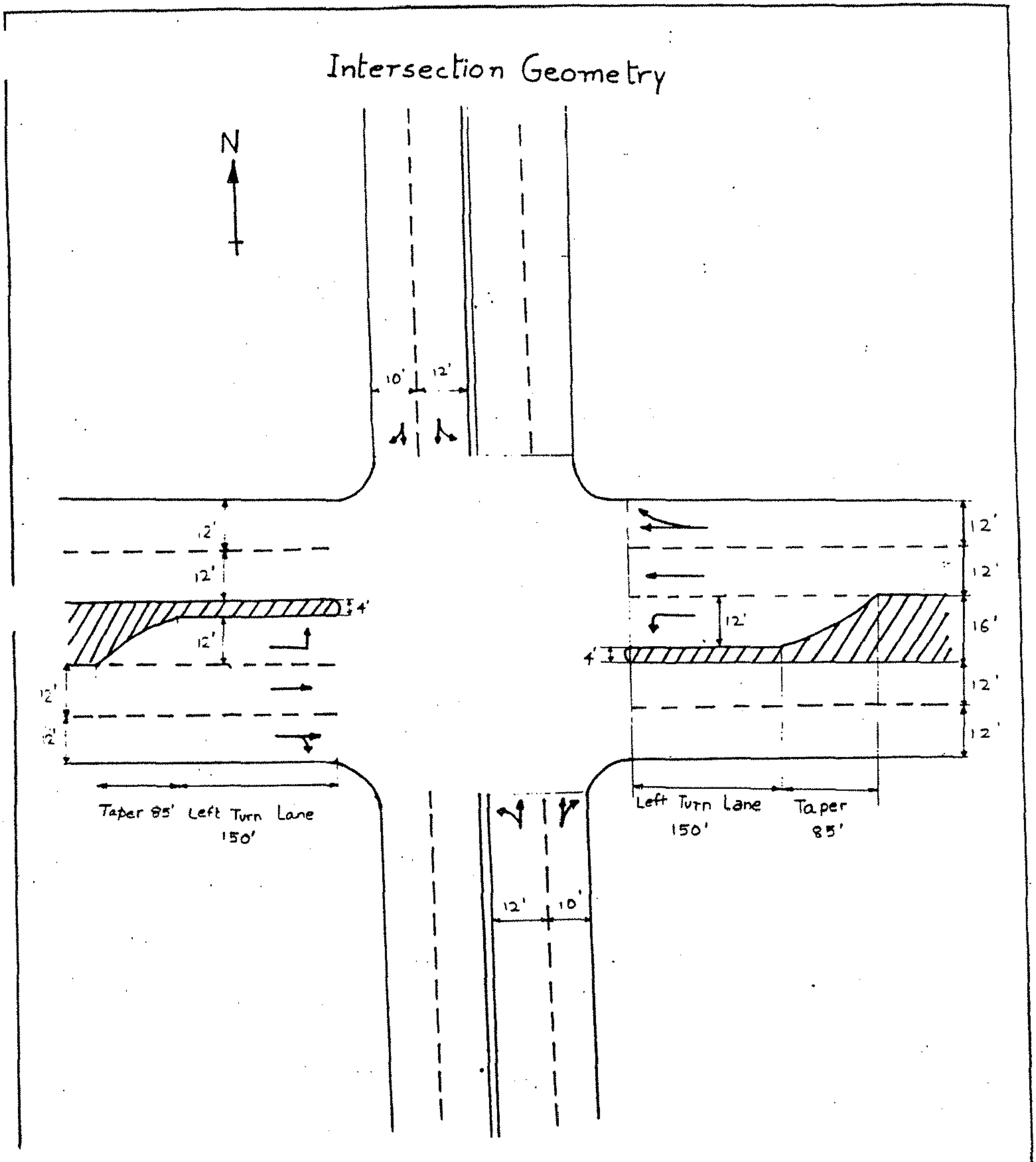
Intersection Geometry
N
10'
12'
12'
12'
4'
12'
12'
12'
12'
12'
12'
16'
12'
4'
12'
12'
Taper 85'
Left Turn Lane
150'
Left Turn Lane
150'
Taper
85'
12'
10'

Figure 1

# APPENDIX B

# CALCULATION OF ACCIDENT RATES

## Annual Average Daily Traffic

The traffic volumes obtained from the different agencies were in the form of peak hour turning movement counts, or annual average daily turning movement counts. The database was developed using AADT, so evening peak hour turning movement counts needed to be converted to AADT. In this appendix, the calculation used to make this conversion is shown. Conversion of peak hour traffic counts and average daily traffic to AADT was done using the reference, "Automatic Traffic Recorders 1982 - 1991," prepared by the Iowa Department of Transportation.

Assume that a traffic volume on a street during the evening peak hour (4:30 PM to 5:30 PM) on an average weekday is "X." An average weekday is typically considered to be a Tuesday, Wednesday, or Thursday when there was no unusual events or weather. Figure 1 contains a graph showing the hourly distribution of daily traffic on municipal streets in Iowa during 1991. Traffic during the evening peak represented about 8% of daily traffic. The factor for converting the evening peak hour traffic to average daily traffic (ADT) was determined as follows:

$$\text{ADT} = X / 0.08$$
$$\text{ADT} = 12.5\ X$$

With this value of ADT, the AADT can be estimated from Figure 2. From the graph in Figure 2 , ADT is about 103% of AADT. To determine the yearly traffic, the following calculations were necessary:

$$\text{ADT} = 103\%\ \text{of AADT}$$
$$12.5\ X = 1.03\ \text{AADT}$$
$$\text{AADT} = 12.5\ X / 1.03$$
$$\text{AADT} = 12.1\ X$$
$$\text{Number of vehicles in one year} = 365\ \text{AADT}$$

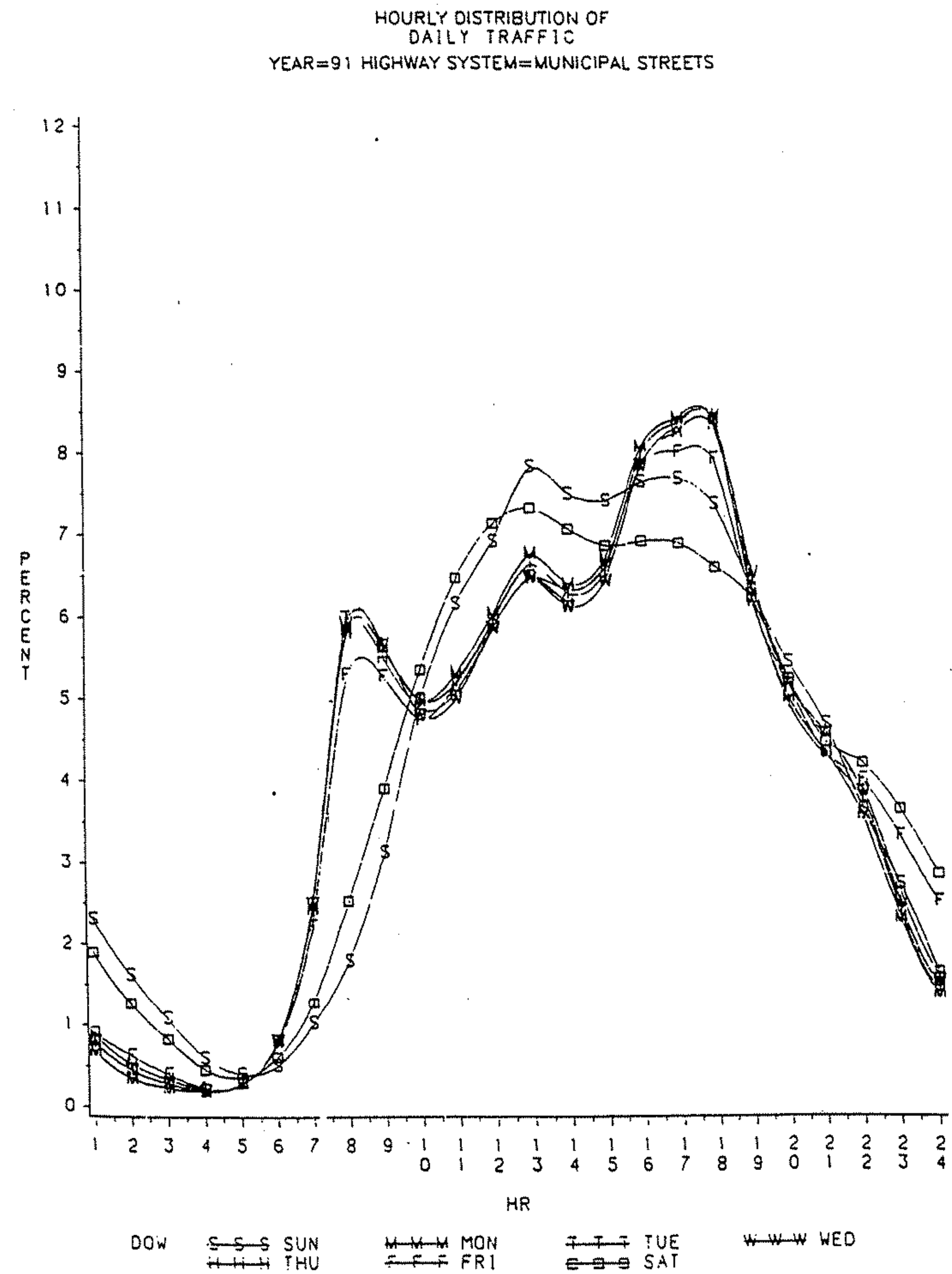


Figure B1: Hourly Distribution of Daily Traffic on Municipal Streets in Iowa During 1991
Source: Automatic Traffic Recorders 1982 - 1991 (Iowa Department of Transportation)

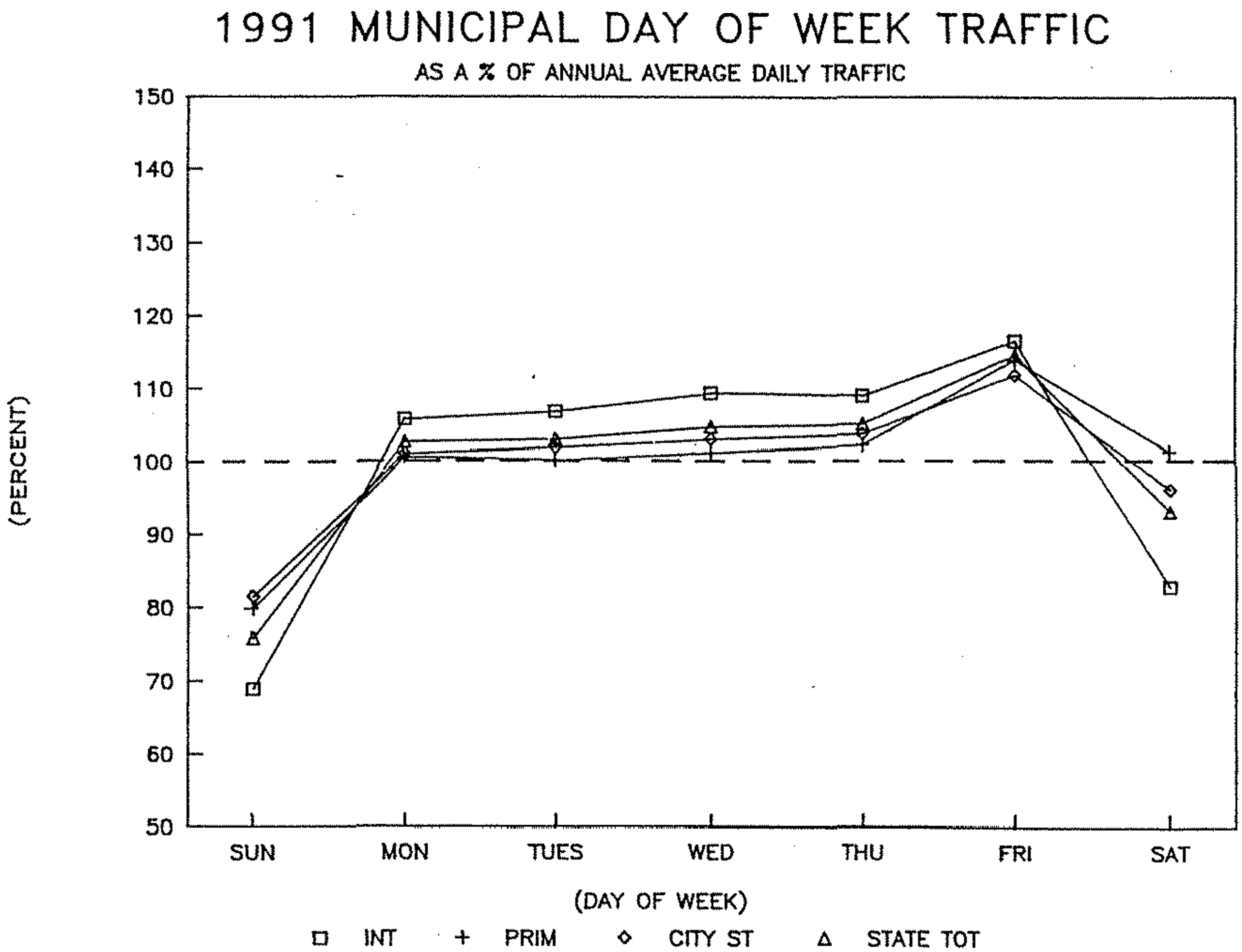


Figure B2: 1991 Municipal Day of Week Traffic in Iowa
Source: Automatic Traffic Recorders 1982 - 1991 (Iowa Department of Transportation)

**Accident Rates**

For the calculation of accident rates, the number of left-turn accidents, and other accidents on an approach in five years were obtained from the ALAS report. The "Left-Turn Accident Rate" (LACCRATE) is the number of left-turn accidents per million left-turning vehicles on the approach. It is calculated as follows:

$$\text{LACCRATE} = \text{No. of Left-Turn Accidents} / \text{No. of Left-Turning Vehicles} \times 10^{-6}$$

The "Approach Accident Rate" (ACCRATE) is the number of accidents on an approach per million vehicles on the approach. It is calculated as follows:

$$\text{ACCRATE} = \text{No. of Approach Accidents} / \text{No. of Approach Vehicles} \times 10^{-6}$$