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16. Abstract

This study was initiated with an extensive literature review and survey of left-turn median lane practices in Texas cities. The initial phase identified characteristics of urban arterial accidents, basic design elements, current use of left-turn lanes, and existing guidelines for left-turn installations. Various study methods for the investigations of operational and accident characteristics were reviewed. One-way analysis of variance and multiple regression techniques were adopted for segments of the analysis. Data were collected, primarily for continuous two-way left-turn median lanes and raised channelized one-way left-turn median lanes, and analyzed through tabulation of accident contributing factors, lateral placement of vehicles in left-turn lane, entering and maneuvering distance in left-turn lane, and other pertinent factors.

An equation and an accident prediction table for CTWLTML's were developed and evaluation guidelines prepared. Based on the study, the utility of left-turn median lanes is substantiated and they are recommended for implementation where appropriate investigation indicates effectiveness. The guidelines contained in this study report are proposed to complement currently acceptable practices, thereby adding to the user confidence of these practices.

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DESIGN CRITERIA FOR MEDIAN TURN LANES

by

C. Michael Walton
Thomas W. Horne
William K. Fung

Research Report Number 212-1F

Design Criteria for Median Turn Lanes
Research Project 3-8-76-212

conducted for

Texas State Department of Highways and Public Transportation
in cooperation with the
U. S. Department of Transportation
Federal Highway Administration

by the

CENTER FOR HIGHWAY RESEARCH
THE UNVERSITY OF TEXAS AT AUSTIN

March 1978

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There was no invention or discovery conceived or first actually reduced to practice in the course of or under this contract, including any art, method, process, machine, manufacture, design or composition of matter, or any new and useful improvement thereof, or any variety of plant which is or may be patentable under the patent laws of the United States of America or any foreign country.

PREFACE

This is the final report on Research Project 3-8-76-212, "Design Criteria for Median Turn Lanes." In addition to the quarterly reports submitted during the project, a technical memorandum entitled "Median Turn Lanes: A Review of Literature and Results of Survey Questionnaire," was prepared and submitted in December 1976. The authors wish to acknowledge and extend their appreciation to the many individuals who have contributed to this research. In particular the study supervisor wishes to acknowledge Dr. William D. Dunlay, Jr., University of Pennsylvania, for his participation while a faculty member at The University of Texas. The assistance of Ray Quay, Henry Chow, Charlie Copeland, Keith Chernicky, and Marsha Hamby was significant in literature review, data collection, and computer programming phases of the research.

Special recognition is extended to Mr. Harold Cooner of D-8 and Mr. Ernest Kanak of D-18 for their guidance and critique during the project. Without the committal of the time and expertise of Mr. Cooner and the others mentioned above, this project would have been greatly impaired.

C. Michael Walton
Study Supervisor

ABSTRACT

This study was initiated with an extensive literature review and survey of left-turn median lane practices in Texas cities. The initial phase identified characteristics of urban arterial accidents, basic design elements, current use of left-turn lanes, and existing guidelines for left-turn installations. Various study methods for the investigations of operational and accident characteristics were reviewed. One-way analysis of variance and multiple regression techniques were adopted for segments of the analysis. Data were collected, primarily for continuous two-way left-turn median lanes and raised channelized one-way left-turn median lanes, and analyzed through tabulation of accident contributing factors, lateral placement of vehicles in left-turn lane, entering and maneuvering distance in left-turn lane, and other pertinent factors.

An equation and an accident prediction table for CTWLTMLs were developed and evaluation guidelines prepared. Based on the study, the utility of left-turn median lanes is substantiated and they are recommended for implementation where appropriate investigation indicates effectiveness. The guidelines contained in this study report are proposed to complement currently acceptable practices, thereby adding to the user confidence of these practices.

KEY WORDS: left-turn lanes, median turn lanes, urban arterials, arterial accidents, continuous two-way, channelized one-way.

SUMMARY

An investigation was initiated to provide highway designers and traffic engineers with more definitive information on the installation of left-turn median lanes. Primary emphasis was on documentation of experiences with continuous two-way left-turn median lanes; however, for comparative reasons, channelized one-way left-turn median lanes (raised and flushed) were included.

This study represents a detailed investigation of the literature pertaining to left-turn lanes, a survey of current practices and standards in the state of Texas, results of field studies, and guidelines suggested for utilization. A literature survey and analysis of the questionnaires returned by representatives from Texas cities and the Texas State Department of Highways and Public Transportation suggested areas in which definitive guidelines were required. Based upon the analysis of these two phases of the study, field studies were conducted which concentrated on operational characteristecs, accident experience, and currently accepted practieces.

The analysis of the data collected on left-turn lane sites revealed many characteristics, patterns, and relationships of accidents in operational experiences. A brief summary of the conclusions and findings of the data analysis are reported herein and guidelines in the form of recommendations are made to complement current practices. For example, equations were developed for estimating accidents per mile on four-lane continuous two-way left-turn median lane sites. This equation should be used as a guide for determining the potential effectiveness of the CTWLTML. In the operational characteristics phase of the study, emphasis was placed on the lateral placement of vehicles in the left-turn lane, and the entering distance and maneuvering distances of vehicles within the lane. These suggest the characteristics of driver behavior which can be used by traffic engineers and highway designers in determining the optimum design elements for two-way left-turn lanes.

IMPLEMENTATION STATEMENT

The efficiency, effectiveness, and reliability of highway design and operational decisions are of paramount importance to every highway and traffic engineer. The highway engineer must have confidence that his techniques will bring the full measure of safety, competence, and maximum utilization of existing facilities to bear for the traveling public. The purpose of this study was to develop guidelines for the design of median treatments in conjunction with non-controlled-access urban arterial highways. The findings of this research provide guidelines presented in a form compatible with current practices. They include traffic operational and geometric design guidelines as well as indicate accident effects and cost effectiveness. In addition, the extensive literature documentation and the survey of current practice in Texas cities provide an overview of operational experience throughout the U.S.

The study was coordinated with representatives of the Texas State Department of Highways and Public Transportation design and traffic engineering personnel to insure readily understandable documentation of findings. The benefits to be accrued include

(1) guidelines for evaluating the effectiveness of median design alternatives for non-controlled-access urban highways,

(2) more efficient and economical procedures for implementation and use of existing facilities,

(3) increased confidence in predicting impact of median improvements on capacity and safety,

(4) increased safety to the traveling public and pedestrians,

(5) increased convenience and decreased delay costs,

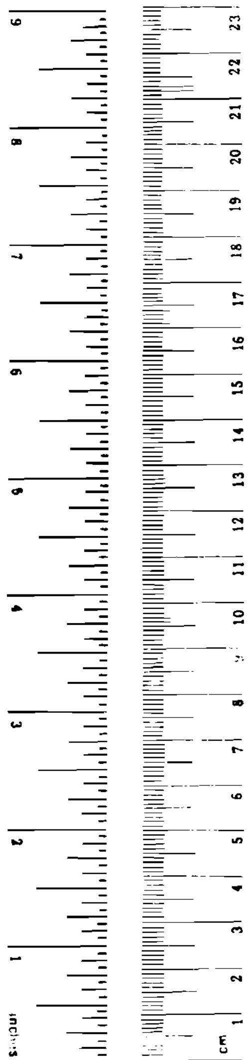
(6) increased energy efficiency, and

(7) low cost alternatives for given traffic and design circumstances compatible with implementation guidelines.

METRIC CONVERSION FACTORS

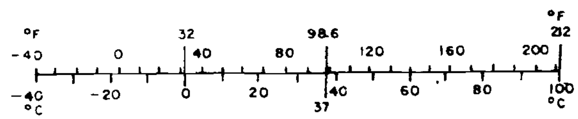
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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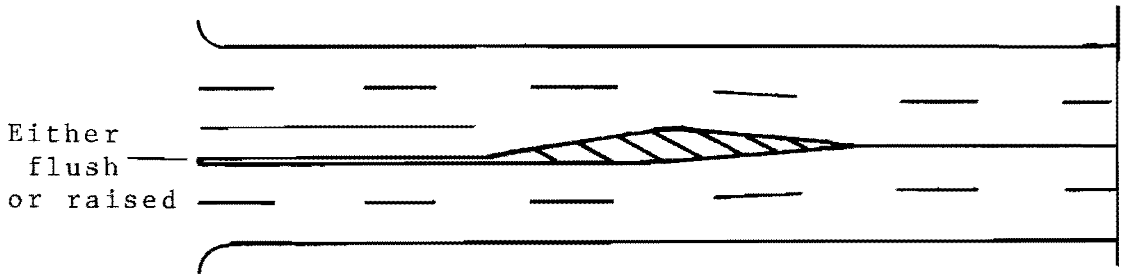
CHAPTER 1. INTRODUCTION

In recent years, there has been increased emphasis on improving the capacity and safety of existing traffic facilities through low cost improvements or modifications. One concern among highway designers and traffic engineers is the treatment of medians on non-controlled-access highways in urban areas and the development of design and operational standards for median improvements. Although many guidelines have been developed to aid traffic engineers in consideration of left-turning vehicles, there are still many unanswered questions as to how and when special median facilities should be provided for these vehicles.

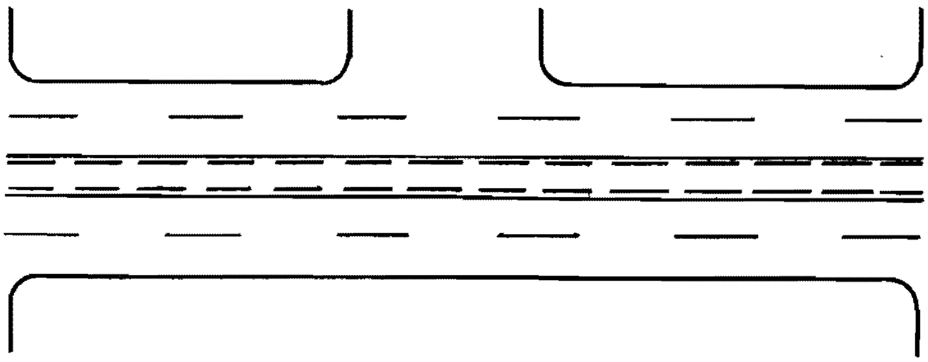
Basically, there are three types of left-turn facilities presented in this study: raised channelized one-way left-turn median lane (raised COWLTML), flush COWLTML, and continuous two-way left-turn median lane (CTWLTML).

A COWLTML (Fig 1.1) is a median left-turn lane which provides space for speed change and storage for left-turn vehicles from only one direction of traffic to turn at a designated location along a two-direction roadway. A CTWLTML is a left-turn median lane which provides common space for speed change and storage for left-turn vehicles traveling in either direction and allows turning movements at any location along a two-way roadway. Raised channelization is generally defined as a curb or other "nontransversible" channelization, while the term flush channelization generally refers to paint, buttons, tiles, or other easily transversible markings.

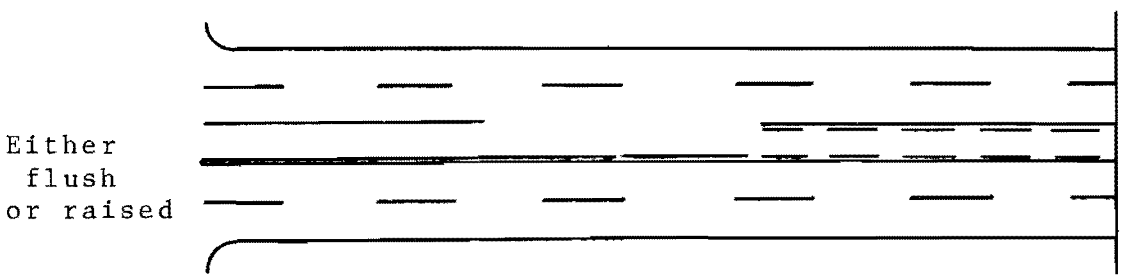
Although these median lanes have been in operation for some time, very little information has been compiled about their operation and differences and tradeoffs between each type of left-turn facility. Therefore, the primary objectives of this study are to (1) review previous studies related to traffic operations of left-turn lanes, (2) collect and analyze data for evaluating the operational characteristics of left-turn facilities, (3) identify relationships and characteristics of accidents associated with left-turn lane facilities, and (4) develop guidelines for design and operational decisions for median



Typical COWLTML



Typical CTWLTML



Transition from CTWLTML to COWLTML

Fig 1.1. Typical types of left-turn lanes.

treatments. The results of this study will enable traffic engineers to better understand the impacts and tradeoffs among various types of left-turn facilities in their decision-making process and will facilitate the design of left-turn lanes for individual sites.

CHAPTER 2. LITERATURE REVIEW

URBAN ARTERIAL ACCIDENTS

As shown in Table 2.1, accidents in urban areas accounted for approximately 72 percent of the vehicle accidents in the United States in 1973, with the majority of these accidents involving two motor vehicles. Table 2.2 shows that almost 86 percent of the accidents in urban areas involved two motor vehicles; the two-motor-vehicle accidents were divided almost equally between intersection and nonintersection locations. Table 2.3 depicts the relative numbers of accidents by type experienced in urban areas in Texas in 1969. Although the figures in Table 2.3 are for passenger cars in Texas (1969), comparison with Table 2.1 shows a similar pattern in the numbers and types of accidents.

It might be assumed that a similar pattern of accident types is occurring in Texas urban areas today. Such an assumption, however, only provides a base for comparing specific locations to the total urban area. Site specific factors will create different patterns at specific locations. One of the most important of these factors is the degree of access control. Figure 2.1 illustrates the effects of access control on total and fatality accident rates in urban areas. In urban areas, the total accident rate under full access control is approximately 35 percent of the rate where there is no access control.

BASIC DESIGN CONSIDERATIONS

Access Considerations

Accident cost and traffic flow conditions are important considerations in determining the need for a left-turn lane and in determining the type and design details of the facility. Due to the importance of these factors, a list is presented below of some of the major considerations in access which may affect safety, traffic flow, cost, feasibility, and public acceptance of left-turn lane designs (Refs 52, 30, and 95).

(1) What is the abutting retailer's preference in type of access?

(2) What is the driver's preference in type of access?

TABLE 2.1. NUMBERS OF ACCIDENTS (URBAN, RURAL, AND TOTAL) BY ACCIDENT TYPE, 1973

ACCIDENT TYPE	NUMBER OF ACCIDENTS		
	URBAN	RURAL	TOTAL
Pedestrian	250,000	50,000	300,000
Two-Motor-Vehicle Collisions, Total	10,200,000	2,800,000	13,000,000
Angle Collisions	3,500,000	700,000	4,200,000
Head-On Collisions	500,000	200,000	700,000
Rear-End Collisions	3,400,000	900,000	4,300,000
Other Two-Vehicle Collisions	2,800,000	1,000,000	3,800,000
Other Collisions	1,200,000	1,300,000	2,500,000
Noncollision	350,000	450,000	800,000
TOTAL ACCIDENTS	12,000,000	4,600,000	16,600,000

Source: National Safety Council, Accident Facts (Ref 97).

TABLE 2.2. DIRECTIONAL ANALYSIS OF VEHICULAR TRAFFIC ACCIDENTS, 1973

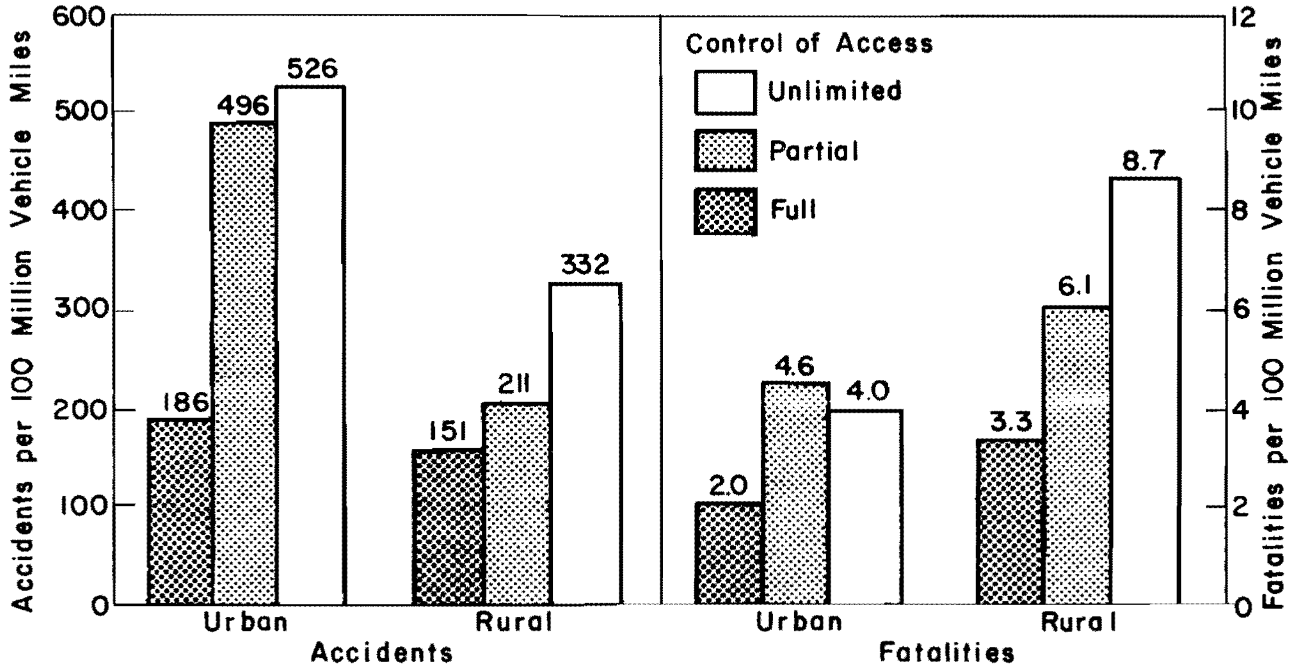
ACCIDENT DESCRIPTION	NUMBER OF ACCIDENTS		
	TOTAL	URBAN	RURAL
Pedestrian	1.9%	2.2%	1.2%
Two Motor-Vehicle Collisions, Total	78.4%	85.7%	59.7%
Intersection	36.5	41.9	22.6
Entering at angle	15.5	17.2	10.8
Entering same direction			
Both going straight	3.3	4.1	1.3
One turn, one straight	3.2	3.4	2.6
One stopped	6.3	7.4	3.6
All others	1.1	1.3	0.4
Entering opposite direction			
Both going straight	1.9	2.5	0.5
One turn, one straight	4.3	5.2	2.1
All others	0.9	0.8	1.3
Nonintersection	41.9%	43.8%	37.1%
Opposite direction-both moving	3.4	2.7	5.0
Same direction-both moving	9.1	8.8	9.9
One car parked	10.3	12.8	4.2
One car stopped in traffic	9.2	9.7	7.9
One car entering parked position	0.3	0.4	0.0
One car leaving parked position	1.6	2.0	0.4
One car entering driveway access	2.3	1.8	3.6
One car leaving driveway access	3.7	3.5	4.2
All others	2.0	2.1	1.9
All Other Collisions	15.1%	9.7%	28.9%
Intersection	2.8	2.8	2.8
Nonintersection	12.3	6.9	26.1
Noncollision	4.6%	2.4%	10.2%
TOTAL ACCIDENTS	100.0%	100.0%	100.0%

Source: National Safety Council, Accident Facts (Ref 97).

TABLE 2.3. REPORTED URBAN INVOLVEMENTS OF PASSENGER CARS BY ACCIDENT TYPE AND SEVERITY, TEXAS, 1969

ACCIDENT TYPE	SEVERITY			
	FATAL	INJURY	P.D.O.	TOTAL
Multi-Vehicle				
Head-On	233	3,163	13,158	16,554
Rear-End	74	21,530	112,908	134,512
Angle	432	29,501	123,690	153,623
Sideswipe	16	1,819	27,647	29,482
Turning	125	9,921	60,290	70,336
Parking	2	347	11,532	11,881
Other	22	2,722	27,892	30,636
Single Vehicle				
Pedestrian	256	3,790	-	4,046
Train	43	233	352	628
Bicycle	20	988	28	1,036
Animal	1	108	628	737
Fixed Object	259	6,743	16,890	23,892
Other Object	0	166	832	998
Noncollision	99	3,110	6,685	9,894
TOTAL ACCIDENTS	1,582	84,141	402,532	488,255

Source: Burke, Dock, Highway Accident Costs and Rates in Texas (Ref 24).



Source: Glennon, John C., et al., Guidelines for the Control of Direct Access to Arterial Highways (Ref 52).

Fig 2.1. Effect of control of access on accidents and fatalities in urban and rural areas.

(3) How is parking affected?

(4) What changes are expected in movement volumes, lane use, traffic composition, etc.?

(5) What pedestrian needs exist or are expected?

(6) What changes in traffic control are anticipated?

(7) What other access does the abutting property have?

(8) What controls are there over driveway location, frequency, etc.?

(9) What other possible uses of the median area now exist or are anticipated?

(10) How might the facility be misused?

Traffic Accidents and Congestion

The following basic causes (or controlling elements) of traffic difficulties as given by Halsey (Ref 58) illustrate the importance of understanding principal relationships between traffic accidents and congestion in designing left-turn lanes. These controlling elements are

(1) angles of movement (including incidence, divergence, and intersection),

(2) velocity differences (if absorbed slowly, produces congestion; if absorbed quickly, produces accidents),

(3) obstructions to movement,

(4) failure of the roadway to make adequate provision for certain functions of movement,

(5) acceptable speed (dependent on area),

(6) ability to pass,

(7) entrances and exits (merging and diverging),

(8) convergence (expanding or constricting no. of lanes), and

(9) capacity (to accommodate volumes).

These basic causes manifest themselves in four types of frictions, and each friction type is just as likely to cause congestion as it is to cause accidents. The four friction types (Ref 58) are

(1) intersectional friction, resulting from right angle movements at intersections,

(2) marginal friction, caused by interferences along the outer edge of the moving traffic stream,

(3) medial friction, cuased by conflicts in the middle of the road between opposing streams of traffic, and

(4) internal-stream friction, caused by differences in speed of vehicles moving in the same direction.

Several references (e.g., Refs 51, 59, 73, and 102) present principles which are intended as guides to aid the traffic engineer in alleviating the basic causes of accidents and traffic congestion.

USE OF LEFT-TURN LANES

A list of warrants and guidelines for use and design of left-turn lanes derived from review of the literature has been previously proposed (Ref 143) as the first phase of this project. Included was a tabulation of the documented conditions under which left-turn lanes have been installed or programed for installation. The following items are a summary of these guidelines.

(1) In general, warrants and guidelines for use of CTWLTML's indicate ADT volumes of 10,000 to 20,000 vehicles per day (vpd) on facilities with four through lanes and 5,000 to 12,000 vpd on facilities with two through lanes.

(2) Warrants and guidelines for use of COWLTML's usually indicate only that the ADT volume should exceed 10,000 vpd. Volumes at COWLTML sites in the literature ranged from 15,400 to 31,200 vpd on facilities with four through lanes.

(3) Through-lane speeds of 30 to 50 miles per hour (mph) are common on CTWLTML sites.

(4) COWLTML's are commonly used on streets where through lane speeds are greater than or equal to 30 mph.

(5) CTWLTML widths range from 10 to 15 feet.

(6) Twelve-foot lane widths are consistently recommended for COWLTML's.

(7) Land uses along CTWLTML sites are most commonly classified as commercial. Some sites are found in industrial areas with commercial activity.

(8) Land use was not found to be as important a consideration at COWLTML sites as it was at CTWLTML sites.

Reference 143 also provides a discussion of an opinions survey of city and state engineers in Texas. Questionnaires were mailed in October 1975 and January 1976 to the 25 District Engineers of the State Department of Highways and Public Transportation (SDHPT) and to engineers in 48 Texas cities ranging in population from approximately 18,000 to 1,233,000 (1970 census figures). The cities were divided into subcategories based on population, i.e., cities over 50,000 population (27) and cities under 50,000 population (21).

The engineers were asked to weight site characteristics in order of importance in determining the type and need for a left-turn lane and to rank CTWLTML's, raised COWLTML's, and flush COWLTML's according to how well each satisfied certain site characteristics. Demand for midblock left turns was ranked as the most important site characteristic followed by (in order of average weight) peak through traffic volume, abutting land use, fewer accidents, restricted sight distance, through traffic speed, number of through lanes, block spacing, pedestrian movements, public (drivers') preference, and abutting retailer's preference.

Although the respondents as a whole showed no distinct preference for left-turn lane type for many street and traffic characteristics, CTWLTML's were preferred over COWLTML's in areas of demand for midblock left-turns, peak through traffic volume, strip commercial land use, through traffic speed over 30 mph, four through lane facilities, long block spacings, drivers' preference, and abutting retailers' preference. COWLTML's were shown as preferred over CTWLTML's by the survey respondents in the areas of restricted sight distance and pedestrian movements. Flush COWLTML's were usually ranked between CTWLTML's and raised COWLTML's.

Other results of this survey are summarized below.

(1) City engineers in Texas indicated that they desired maximum speed limits in CTWLTML's to be less than the usual posted speed limit for arterial street through lanes, yet speed limits for CTWLTML's are rarely posted. In many of the references COWLTML's are commonly used on streets where through lane speeds are greater than or equal to 30 mph.

(2) Guidelines suggested for CTWLTML widths range from 10 to 15 feet. The survey also indicated that engineers in Texas desire the CTWLTML width to increase as the through lane speed increases. Survey responses consistently recommended 12-foot lane widths for COWLTML's and indicate that minimum widths smaller than those for CTWLTML's are tolerable.

(3) Major effects which the survey respondents believed to be due to left-turn lane installations include substantial (yet sometimes varied) effects on the number of accidents (especially those involving left-turn vehicles), capacity, delay, and travel time at the sites.

(4) Engineers in Texas who responded to the survey had an average of only about five years personal experience with CTWLTML's. City engineers had about three years more experience with COWLTML's, and district engineers had about six years more experience with COWLTML's, on the average.

(5) Engineers in Texas have a wide range of opinions on left-turn lane design practices and conditions for use.

(6) Texas engineers generally feel that CTWLTML's are more frequently misused than COWLTML's and show considerable variation in what is considered proper use of MLTL's.

(7) Approximately one-half of the district engineers responding to the survey and three-quarters of the city engineers responding use different signs and markings at major intersections than at midblock locations on CTWLTML's. The most common difference was the transition of the CTWLTML to a COWLTML with inclusion of a gap in the marking for entering the lane.

(8) Survey respondents as a whole showed no distinct preference on left-turn lane type for many street and traffic characteristics.

Characteristics of Left-Turn Lanes

The proper installation of any type of left-turn lane will have positive effects on traffic flow and accidents. Each type of left-turn lane also has certain advantages over the other types.

CTWLTML's have several advantages over raised COWLTML's. CTWLTML's provide continuous access to the abutting land and alleviate problems which may be caused by concentrations of left-turning vehicles. Flexible storage and deceleration lengths are also provided, which may be an important advantage even in short block situations and on sections with few midblock left-turns. The flush markings of CTWLTML's allow the median area to be used by emergency vehicles, by vehicles which must make emergency stops, and by through vehicles as a through lane when another lane must be blocked. CTWLTML's may be used by entering traffic as an acceleration lane (which is considered a misuse of the lane in some references). The lane design also allows access by large vehicles with greater ease and eliminates many U-turns at nearby intersections.

Raised COWLTML's, however, offer several advantages over CTWLTML's. Raised islands control possible vehicle movements, control vehicle paths, focus conflict types at fewer locations, provide a more positive separation of traffic flow from the opposing direction, reduce the number of potential misuses of the facility, control the number and spacing of traffic interruptions, provide pedestrian refuge areas, and provide locations for traffic control devices. Raised COWLTML's have greater visibility than CTWLTML's and eliminate the need for driver education where CTWLTML's have not been introduced to a majority of the driving public. Raised COWLTML's may also be used, with the cooperation of land developers, to establish efficient access to abutting property in a planned and controlled manner.

RELATED STUDIES

Studies which are related to left-turn lanes range from individual installation studies to projects covering a wide range of improvements. These studies have provided a great deal of valuable information to aid in understanding effects of left-turn installations; however, application of the findings of these studies to warrants is difficult because the relationships between accidents and site characteristics have not been fully determined. Previous studies related to left-turn lanes may be generally classified as before-after (or parallel) accident studies, operational studies (which may also be before-after studies), general access studies, and studies using regression techniques.

Before-after accident studies and operational studies may include many sites or focus on a particular site. These studies have been valuable in describing the magnitude of expected improvements and in defining how drivers react to various designs. General access studies are those related to identifying improvements and policies (e.g., Ref 95) and to evaluation of access techniques through a review of literature and estimation of effects due to improvements (e.g., Ref 51). Only a few related studies have used regression techniques (e.g., Refs 44 and 91), but those studies were not investigations related to specific left-turn lane types in an urban setting. The summary of findings and recommendations presented below draws primarily from the more extensive studies which have been performed in relation to left-turn lanes.

Operational Studies on CTWLTML

Studies on CTWLTML have been done by a variety of state and local agencies, but most were focused on accidents and only a few were related to traffic operational aspects. With respect to operational aspects of CTWLTML, two major studies were found. One was conducted by Sawhill and Neuzil of the University of Washington (Ref 117), and another was conducted by Nemeth of Ohio State University (Ref 103).

Sawhill and Neuzil (Ref 117) made their operational study in terms of travel distance within a CTWLTML prior to a left-turn maneuver during rush and non-rush hours, general observations and commentary on users' behavior related to CTWLTML, and the use of vehicle turn-signal indicators prior to a left-turn maneuver. Their findings include the following observations.

(1) Those people who don't understand the CTWLTML tend to slow down or stop in the through lane before making a left turn.

(2) Seventeen percent of the out-of-town drivers make their left turns from the through lane without making use of the CTWLTML.

(3) Most drivers complete the left-turn entry maneuver into the left-turn lane within 40 to 50 feet of beginning the entry or of the intersection.

(4) The average travel distance within a CTWLTML for the local driver is 200 feet and for the out-of-town driver is 140 feet.

(5) Travel distance on a CTWLTML is longer during the rush hour than during the non-rush hour for the local driver, but relatively consistent for the out-of-town driver.

(6) Drivers decelerate in the through lane before entering the CTWLTML.

(7) Automobiles entering the roadway from driveways make little use of the CTWLTML as an acceleration lane; however, truckers do make use of it for their left-turn movement.

(8) Few drivers use the CTWLTML as a passing lane.

(9) Approximately 80 percent of the drivers use their turn signal indicators prior to a left turn into a driveway, and only 40 percent signal when entering the roadway from a driveway.

Sawhill and Neuzil also stated that additional research in signing is needed to familiarize the out-of-town drivers with the proper use of the CTWLTML. It was recommended that the width of the median lane be 10 to 13 feet.

Nemeth (Ref 103) initiated four "before and after" operational studies on CTWLTML in Ohio. His major parameters were traffic conflicts, travel time, left and right turning volumes, and traffic volume on each lane. Traffic conflict as defined by Nemeth is "any instance in which a main flow vehicle must either swerve or brake to avoid an accident." He further classified the conflicts into cross conflict, opposing conflict, rear-end conflict, and weaving. Cross conflict is defined as "a traffic conflict due to the actions of cross traffic," opposing conflict is defined as "a traffic conflict caused by an opposing left-turn vehicle," rear-end conflict is defined as "a traffic conflict due to the actions of a proceeding car," and, finally, weaving occurs when "a vehicle strays out of its lane to the point that either its left wheel crosses the center line or its right wheel crosses onto the right shoulder."

Due to unanticipated circumstances only two sites were studied in a "before and after" context. One site involved the conversion of a four-lane arterial into a three-lane roadway. The other site involved the restriping of a four-lane highway section into a five-lane section.

The conclusion of the analysis of the first site was that the conversion resulted in increased travel times, increased weaving, and some observed reduction in conflicts. In the second case an increase in volumes was noted, with an insignificant change in travel speeds. Conflicts attributable to braking were noted to have decreased after some initial increase due to driver confusion with the pavement markings.

The net result of the study was the development of "guidelines" which present relevant discussions on topical areas such as adjacent land use, access conditions and requirements, traffic volume, speed limit, spacing of existing intersections, economic conditions and safety. A general strategy for considering CTWLTML is provided in discussion format.

Operational Studies on COWLTML

Rowan (Ref 103) performed a study on channelization by measuring the tension of drivers through a highway study section. He performed the study during the three stages of a channelization installation. The first stage had no channelization, and the final stage had a divisional island with a special approach-end treatment. The results were inconclusive due to the small number of responses and the variability in drivers. Rowan also performed a speed study before and after the installation of divisional island channelization. Those results were also inconclusive.

Shaw and Michael (Ref 120) conducted a study to aid in the establishment of warrants for the implementation of left-turn lanes in Indiana. They collected delay and accident rate data at eleven intersections and used multiple regression techniques to develop equations to predict suburban delay time, rural delay time, suburban accident rates, and rural accident rates in terms of several operational variables. Their final presentation was a cost-benefit analysis where the cost was the construction cost and the benefits were the reduction in accidents and delay.

Another element considered to be an important left-turn operational characteristic is gap acceptance. Ring and Carstens (Ref 111) classified the gap characteristics into gap, lag critical gap, and critical lag. Gap is defines as "the headway in the traffic stream opposing a vehicle that is stopped preparatory to effecting a left-turn maneuver." Lag is defined as "that portion of a gap between the time of arrival of a left-turn vehicle (that has not stopped) at a point where it encroaches upon the opposite traffic lane and the arrival at the same point of an opposing vehicle." The critical lag or gap is defined as "one of the duration such that the same number of vehicles have accepted a lag or gap of the length or shorter as have rejected one of that length or longer." Their findings on critical gaps and lags were later applied in a theoretical model to ascertain its accuracy.

However, the results observed from the site investigation contradicted the results obtained from the theoretical model. Several possible reasons were stated for this disagreement:

(1) A driver might take a risk in accepting a shorter lag if there is a longer line of traffic behind the car that will conflict with his left turn.

(2) A driver might reject a longer lag if he sees only one vehicle approaching in the opposite traffic.

(3) A driver adjusts the speed of the vehicle with respect to the lag available to minimize the possibility of stopping.

These behavioral aspects while concluded as difficult to predict were put in a multiple regression model to estimate the number of vehicles that were forced to stop and the magnitude of delays to the stopped vehicles. Their final presentations were two equations for estimating the cost-benefit ratio where the cost was the construction cost and the benefit was the accident reduction and delay savings.

Another left-turn gap acceptance study was conducted by Dart (Ref 32) at both channelized and unchannelized approach signalized intersections. He found that drivers rarely accepted a gap of less than two seconds or rejected a gap longer than eight seconds. Based on his analysis of gap acceptance, he concluded that there was no appreciable difference between channelized and unchannelized approaches.

Volume Warrants. Volume warrants for left-turn lanes are typically presented in graphical form and relate percent of left-turning traffic to other volumes. Ring and Carstens (Ref 111) developed a series of graphs for determining if a left-turn lane is warranted at a rural intersection which also account for the posted speed, the annual accident cost reduction, and the percent of trucks. Glennon et al. (Ref 52) presents a volume warrant chart for sections or intersections which requires the percentage of left-turns, advancing volume, and opposing volume.

Accidents at Channelized Intersections. Accident studies related to left-turn lanes at intersections (or high volume driveways) have found significant decreases in accident rates where one-way left-turn lanes were added. Wilson (Ref 149) presented a summary of before-after studies which compared channelized left-turn lanes at unsignalized intersections using raised bars, curbs, and paint for channelization. Table 2.4 shows the comparison, along with a comparison of painted left-turn channelization projects in urban and rural areas. This also shows statistically significant reductions in accident rates for projects using all types of channelization. Painted channelization projects showed a 32 percent reduction in accident rate, and curbed and raised bar channelization projects showed reductions of 64 percent and 69 percent, respectively. Painted channelization projects showed a 15 percent reduction in accident rates in urban areas, which was not statistically significant, and a 50 percent reduction in accident rates in rural areas, which was statistically significant.

Foody and Richardson (Ref 43), in a comparison of intersections with and without left-turn lanes, found a great deal of variability in accident rates. Table 2.5 shows the comparison of sites Foody and Richardson developed on a basis of signalization and the existence of a left-turn lane. Although significant differences were shown in comparing total accident rates, the variability of left-turn accident rates made the subset averages for the left-turn accident rates show no statistical difference.

Shaw and Michael (Ref 120) used multiple regression to evaluate delays and accidents at intersections. Equations were developed for estimation of delays and accidents at suburban intersections with left-turn lane channelization which explained 69 percent of the variation in delay and 61 percent of the variation in accident rates with eight and seven variables respectively. The most important variables in predicting the accident rate were related to average daily traffic (ADT), the number of approach lanes, and the average speeds of nondelayed through vehicles.

Accident Experiences on Designated Sections. Glennon et al. (Ref 52) evaluated numerous access techniques, utilizing information available in literature and estimating average values of accidents, running times, cost benefit ratios, and other measures of effectiveness. Tables 2.6 and 2.7 show the general accident warrants for access control techniques developed for left-turn and total accident rates on routes or at points. Tables 2.8, 2.9, and 2.10 show the estimates of accident reductions for COWLTML's and CTWLTML's.

TABLE 2.4. BEFORE-AFTER ACCIDENT RATES FOR LEFT-TURN CHANNELIZATION PROJECTS

LEFT-TURN CHANNELIZATION
(Unsignalized)

			Projects: Total No.	Projects: Improved	Projects: Worsened	Projects: No Change	Years of Experience	Single Vehicle: Ran off Road	Single Vehicle: Other	Single Vehicle: Sub-Total	Multiple Vehicle: Left Turn	Multiple Vehicle: Rear End	Multiple Vehicle: Crossing	Multiple Vehicle: Other	Multiple Vehicle: Sub Total	Severity: PDO	Severity: Injury	Severity: Fatal	LT Cond.: Day a/	LT Cond.: Night a/	Total Accidents	Million Vehicles	Equivalent PDO (EPDO)	Severity Index (SI)
Painted	Before	No. of Accidents	27				31 2/12	11	4	15	37	68	27	10	142	84	71	2	98	59	157	134.5	522	3.3
		Rate						0.08	0.03	0.11	0.28	0.51	0.20	0.07	1.06	0.62	0.53	0.01	1.09	1.33	1.17		3.88	
	After	No. of Accidents	27	2^{S}	0	25	31 2/12	16	2	18	24	17^{S}	37	10	88^{S}	64	40^{S}	2	58^{S}	48	106^{S}	134.1	316	3.0
		Rate						0.12	0.01	0.13	0.18	0.13	0.28	0.07	0.66	0.48	0.30	0.01	0.65	1.08	0.79		2.36	
		% Rate Change						+50	-67	+18	-36	-75	+40	0	-38	-23	-43	0	-40	-19	-32		-39	
Curbed	Before	No. of Accidents	7				10	1	6	7	4	36	6	8	54	44	15	2	38	23	61	68.8	146	2.4
		Rate						0.01	0.09	0.10	0.06	0.52	0.09	0.12	0.78	0.64	0.22	0.03	0.85	1.00	0.89		2.12	
	After	No. of Accidents	7	3^{S}	0	4	10	3	1^{S}	4	4	4^{S}	10	3	21^{S}	22^{S}	3^{S}	0	18^{S}	7^{S}	25^{S}	77.7	40	1.6
		Rate						0.04	0.01	0.05	0.05	0.05	0.13	0.04	0.27	0.28	0.04	0	0.35	0.27	0.32		0.51	
		% Rate Change						+300	-89	-50	-17	-90	+44	-67	-66	-56	-82	-100	-58	-73	-64		-76	
Raised Bars	Before	No. of Accidents	6				9	5	2	7	11	60	6	11	88	54	40	1	67	28	95	66.4	300	3.2
		Rate						0.08	0.03	0.11	0.17	0.90	0.09	0.17	1.33	0.81	0.60	0.02	1.51	1.27	1.43		4.52	
	After	No. of Accidents	6	4^{S}	0	2	9	6	0	6	5	3^{S}	13	4^{S}	25^{S}	18^{S}	12^{S}	1	18^{S}	13^{S}	31^{S}	69.6	96	3.1
		Rate						0.09	0	0.09	0.07	0.04	0.19	0.06	0.36	0.26	0.17	0.01	0.39	0.56	0.45		1.38	
		% Rate Change						+12	-100	-18	-59	-96	+111	-65	-73	-68	-72	-50	-74	-56	-69		-69	
Total	Before	No. of Accidents	40				50 2/12	17	12	29	52	164	39	29	284	182	126	5	203	110	313	269.7	968	3.1
		Rate						0.06	0.04	0.11	0.19	0.61	0.14	0.11	1.05	0.67	0.47	0.02	1.12	1.24	1.16		3.59	
	After	No. of Accidents	40	9^{S}	0	31	50 2/12	25	3^{S}	28	33^{S}	24^{S}	60^{S}	17^{S}	134^{S}	104^{S}	55^{S}	3	94^{S}	68^{S}	162^{S}	281.5	452	2.8
		Rate						0.09	0.01	0.10	0.12	0.08	0.21	0.06	0.48	0.37	0.20	0.01	0.50	0.73	0.58		1.61	
		% Rate Change						+50	-75	-9	-37	-87	+50	-45	-54	-45	-57	-50	-55	-41	-50		-55	

a/ Assume 2/3 MV for Day and 1/3 MV at night for rate calculations.
"S" Indicates change is significant at the 0.10 level using the Chi Square Test.

LEFT-TURN CHANNELIZATION
(Painted)

			Projects: Total No.	Projects: Improved	Projects: Worsened	Projects: No Change	Years of Experience	Single Vehicle: Ran off Road	Single Vehicle: Other	Single Vehicle: Sub-Total	Multiple Vehicle: Left Turn	Multiple Vehicle: Rear End	Multiple Vehicle: Crossing	Multiple Vehicle: Other	Multiple Vehicle: Sub Total	Severity: PDO	Severity: Injury	Severity: Fatal	LT Cond.: Day a/	LT Cond.: Night a/	Total Accidents	Million Vehicles	Equivalent PDO (EPDO)	Severity Index (SI)
Urban	Before	No. of Accidents	12				12 10/12	4	4	8	18	34	14	5	71	43	35	1	45	34	79	67.4	259	3.3
		Rate						0.06	0.06	0.12	0.27	0.50	0.21	0.07	1.05	0.64	0.52	0.01	1.00	1.53	1.17		3.84	
	After	No. of Accidents	12	1^{S}	0	11	12 10/12	6	2	8	14	11^{S}	26^{S}	8	59	43	23	1	33	34	67	66.7	187	2.8
		Rate						0.09	0.03	0.12	0.21	0.16	0.39	0.12	0.88	0.64	0.34	0.01	0.74	1.54	1.00		2.80	
		% Rate Change						+50	-50	0	-22	-68	+86	+71	-16	0	-35	0	-26	+1	-15		-27	
Rural	Before	No. of Accidents	15				18 4/12	7	0	7	19	34	13	5	71	41	36	1	53	25	78	67.1	263	3.4
		Rate						0.10	0	0.10	0.28	0.51	0.19	0.07	1.06	0.61	0.54	0.01	1.18	1.13	1.16		3.92	
	After	No. of Accidents	15	1^{S}	0	14	18 4/12	10	0	10	10	6^{S}	11	2	29^{S}	21^{S}	17^{S}	1	25^{S}	14	39^{S}	67.4	129	3.3
		Rate						0.15	0	0.15	0.15	0.09	0.16	0.03	0.43	0.31	0.25	0.01	0.55	0.63	0.58		1.91	
		% Rate Change						+50	0	+50	-46	-82	-16	-57	-59	-49	-54	0	-53	-44	-50		-51	
Total	Before	No. of Accidents	27				31 2/12	11	4	15	37	68	27	10	142	84	71	2	98	59	157	134.5	522	3.3
		Rate						0.08	0.03	0.11	0.28	0.51	0.20	0.07	1.06	0.62	0.53	0.01	1.09	1.33	1.17		3.88	
	After	No. of Accidents	27	2^{S}	0	25	31 2/12	16	2	18	24	17^{S}	37	10	88^{S}	64	40^{S}	2	58^{S}	48	106^{S}	134.1	316	3.0
		Rate						0.12	0.01	0.13	0.18	0.13	0.28	0.07	0.66	0.48	0.30	0.01	0.65	1.08	0.79		2.36	
		% Rate Change						+50	-67	+18	-36	-75	+40	0	-38	-23	-43	0	-40	-19	-32		-39	

a/ Assume 2/3 MV for Day and 1/3 MV at night for rate calculations.
"S" Indicates change is significant at the 0.10 level using the Chi Square Test.

Source: Wilson, James, E., "Simple Types of Intersection Improvements," (Ref 149).

TABLE 2.5. ACCIDENT RATES AT INTERSECTIONS WITH AND WITHOUT LEFT-TURN LANES

Accidents Per Million Vehicles Per Leg Per Year
(Classifications: Signalization, Left-Turn Lane)

	Non-Signalized		Signalized	
	With LTL	Without LTL	With LTL	Without LTL
Number of Legs	33	134	61	135
Left-Turn Accident Rate	0.12	1.20	0.37	0.65
All Others Accident Rate	0.92*	3.15*	1.17*	1.82*
All Accident Rate	1.04*	4.35*	1.54*	2.47*

*Significant difference (0.05 significance level)

Source: Foody and Richardson, "Evaluation of Left-Turn Lanes as a Traffic Control Device," (Ref 43).

TABLE 2.6. LEFT-TURN ACCIDENT WARRANTS FOR ACCESS CONTROL TECHNIQUES

Route Techniques

(Annual Number of Driveway-Related Accidents per Mile)

LEVEL OF DEVELOPMENT (Driveways per Mile)	HIGHWAY ADT (Vehicles per Day)		
	LOW <5,000	MEDIUM 5-15,000	HIGH >15,000
LOW <30	2.66	5.18	7.70
MEDIUM 30-60	7.91	15.47	23.03
HIGH >60	10.50	20.58	30.66

Point Techniques

(Annual Number of Accidents)

DRIVEWAY ADT (Vehicles per Day)	HIGHWAY ADT (Vehicles per Day)		
	LOW <5,000	MEDIUM 5-15,000	HIGH >15,000
LOW <500	0.18	0.31	0.43
MEDIUM 500-1500	0.44	0.77	1.05
HIGH >1500	0.68	1.19	1.61

Source: Glennon, John C., et al., Guidelines for the Control of Direct Access to Arterial Highways, (Ref 52).

TABLE 2.7. TOTAL ACCIDENT WARRANTS FOR ACCESS CONTROL TECHNIQUES

Route Techniques

(Annual Number of Driveway-Related Accidents per Mile)

LEVEL OF DEVELOPMENT	HIGHWAY ADT (Vehicles per Day)		
	LOW	MEDIUM	HIGH
(Driveways per Mile)	<5,000	5-15,000	>15,000
LOW <30	3.8	7.4	11.0
MEDIUM 30-60	11.3	22.1	32.9
HIGH >60	15.0	29.4	43.8

Point Techniques

(Annual Number of Accidents)

LEVEL OF DEVELOPMENT	HIGHWAY ADT (Vehicles per Day)		
	LOW	MEDIUM	HIGH
(Vehicles per Day)	<5,000	5-15,000	>15,000
LOW <500	0.26	0.44	0.62
MEDIUM 500-1500	0.63	1.10	1.50
HIGH >1500	0.97	1.70	2.30

Source: Glennon, John C., et al., Guidelines for the Control of Direct Access to Arterial Highways, (Ref 52).

TABLE 2.8. ANNUAL ACCIDENT REDUCTION PER MILE BY INSTALLING RAISED MEDIAN DIVIDER

(Raised COWLTML)

LEVEL OF DEVELOPMENT (Driveways per Mile)		HIGHWAY ADT (Vehicles per Day)		
		LOW <5,000	MEDIUM 5-15,000	HIGH >15,000
LOW	<30	2.2	4.1	6.3
MEDIUM	30-60	5.8	11.2	17.2
HIGH	>60	10.7	20.7	31.2

Source: Glennon, John C., et al., Guidelines for the Control of Direct Access to Arterial Highways, (Ref 51).

TABLE 2.9. ANNUAL ACCIDENT REDUCTION PER MILE BY INSTALLING ALTERNATING LEFT-TURN LANE

(Flush COWLTML)

LEVEL OF DEVELOPMENT (Driveways per Mile)		HIGHWAY ADT (Vehicles per Day)		
		LOW <5,000	MEDIUM 5-15,000	HIGH >15,000
LOW	<30	1.7	3.2	5.1
MEDIUM	30-60	3.5	7.1	11.6
HIGH	>60	6.9	13.3	21.0

Source: Glennon, John C., et al., Guidelines for the Control of Direct Access to Arterial Highways, (Ref 52).

TABLE 2.10. ANNUAL ACCIDENT REDUCTION PER MILE BY INSTALLING TWO-WAY LEFT-TURN LANE

(CTWLTML)

LEVEL OF DEVELOPMENT (Driveways per Mile)	HIGHWAY ADT (Vehicles per Day)		
	LOW <5,000	MEDIUM 5-15,000	HIGH >15,000
LOW <30	4.4	8.8	13.3
MEDIUM 30-60	7.1	13.9	20.9
HIGH >60	9.7	19.0	28.6

Source: Glennon, John C., et al., Guidelines for the Control of Direct Access to Arterial Highways, (Ref 52).

For raised COWLTML's it was assumed that accidents would be reduced by 50 percent at intersections and major driveways and that at minor driveways all left-turn accidents would be eliminated and there would be a slight increase in right-turn accidents. For flush COWLTML's it was assumed that accidents would be reduced by 28 percent, and for CTWLTML's, 35 percent.

Other references have already shown that there is a great deal of variability in reductions of accidents for channelized lanes. Table 2.11 shows that there is also a great variability in accident reductions due to CTWLTML installations. The variabilities in accident reductions, and their unaccountability, make applications of reductions to a specific proposed installation very difficult.

SUMMARY

No quantitative information related to both channelized one-way left-turn median lanes (COWLTML's) and continuous two-way left-turn median lanes (CTWLTML's) was found in any single reference. Only subjective comments regarding both types of left-turn lanes were found. Accident analysis on a particular type of left-turn lane was the common approach of the few studies regarding left-turn lanes. Operational characteristics were mentioned only in a few of those studies. The common study elements were delays and gap acceptance on COWLTML and conflicts and entrance distance on CTWLTML.

Previous studies related to left-turn lanes and access provisions have provided much valuable information to aid in selecting and designing left-turn-lane facilities. However, additional knowledge is still needed to relate accident numbers and rates to site conditions. Several studies have provided detailed analyses of left-turn channelization at intersections: however, much additional information is needed on the improvement effects over sections of roadways.

TABLE 2.11. CTWLTML BEFORE-AFTER STUDIES

<table>
<tr><th></th><th>Conradson and Al-Ashari (Ref 31)</th><th>Busbee (Ref 25)</th><th colspan="2">Sawhill and Neuzil (Ref 113)</th></tr>
<tr><td>Number of Sections</td><td>4</td><td>1</td><td>1</td><td>1</td></tr>
<tr><td>Total Length</td><td>6.58 mi.</td><td>1.7 mi.</td><td>1.03 mi</td><td>1.49 mi</td></tr>
<tr><td>No. of Through Lanes</td><td>4</td><td>4</td><td>4</td><td>4</td></tr>
<tr><td>Date(s) Installed</td><td>1964-1969</td><td>1974</td><td>1958</td><td>1961</td></tr>
<tr><td>Before Period</td><td>1 yr</td><td>1 yr</td><td>4 yr</td><td>3 yr</td></tr>
<tr><td>After Period</td><td>1 yr</td><td>1 yr</td><td>4 yr</td><td>1 yr</td></tr>
<tr><td>Change in No. of Accidents</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Total</td><td>-33%</td><td>-38%</td><td>-26%</td><td>-6%</td></tr>
<tr><td>Left-Turn</td><td>-45%</td><td rowspan="2">-90%</td><td>+140%</td><td>-29%</td></tr>
<tr><td>Rear-End</td><td>-62%</td><td>-28%</td><td>-19%</td></tr>
<tr><td>Right-Angle</td><td>+14%</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>Sideswipe</td><td>-7%</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>Other</td><td>+6%</td><td>-</td><td>-30%</td><td>+16%</td></tr>
</table>

CHAPTER 3. METHODOLOGY

Several analysis techniques have been used in the study of traffic accidents and operational characteristics of left-turn median lanes to evaluate relationships which may exist between pertinent variables. The purpose of this chapter is to review analysis techniques which might be applicable to the study of left-turn lanes and to present the selected technique utilized in this study.

ANALYSIS TECHNIQUES

The technique chosen for an accident or operational study depends primarily upon the nature of the available data and the study objectives. In most research applications dealing with design features of roadways, the purpose of accident and operational analysis is to investigate relationships between these parameters and various site or roadway characteristics for a number of chosen cases in order that the effects of certain conditions can be estimated. Four common analysis techniques used in such studies are (1) regression analysis, (2) before-after studies, (3) comparison and individual case studies, and (4) performance standard studies.

Regression Analysis

Regression analysis is usually expressed as a technique for fitting a predictive equation (called a regression equation) to data and is normally expressed in the form

$$Y_i = B_0 + B_1X_{1i} + B_2X_{2i} \cdot\ .\ .B_nX_{ni} + \varepsilon_i$$

where Y_i is the predicted value of a dependent variable for given values of the independent variables X_{1i}, X_{2i},. . .X_{ni} ; B_0 is the Y-intercept; B_1, B_2. . .B_n are partial regression coefficients which estimate how a unit change in the corresponding independent variable would change the dependent variable provided the other independent variables are held constant; and ε_i is the error associated with the predicted value of Y_i. The basic assumptions of the regression analysis are

(1) ε_i and ε_j are uncorrelated and $i \neq j$, so that the covariance of ε_i and ε_j is zero. Thus the expected value of Y_i is

$$E(Y_i) = B_0 + B_1X_{1i} + B_2X_{2i} \cdot \cdot \cdot B_nX_{ni}$$

the variance of $Y_i = \sigma^2$, and Y_i and Y_j, $i \neq j$, are uncorrelated; and

(2) ε_i is a normally distributed random variable with mean zero and variance σ^2 (unknown).

There are numerous statistics and analysis methods to describe the usefulness of the predictive equation. However, the final result of a regression analysis need not be a predictive equation; the technique may be simply used as a test of significant relationships among variables and as an aid for identifying extreme situations, possible transformations of data, and important group separations of the data (through dummy variables). Regression analysis is not directly used to determine effects of an improvement over a previous situation; however, comparisons between sets of conditions may be made through comparisons of developed equations or through comparisons of dummy dependent variables (discriminant analysis). Misuses of regression analysis include prediction beyond the range of independent variables, improper use of dummy variables, poor analysis of residuals, heavy reliance on only one or two of the available descriptive statistics, failure to recognize possible subset equations, and failure to recognize noncausal relationships.

Before-After Studies

Before-after studies are frequently used to investigate effects of changes at a specific site or set of sites. It is assumed that the only changes which occur at the sites are controlled and that the effects on accidents, speeds, etc. are directly related to the controlled changes. This method of analysis isolates the particular designs or controls being investigated to a great extent and gives a direct measure of the effects of the changes. Some common sources of mistakes in before-after studies (Ref 21) are

(1) poor choice of periods of time for before and after data,

(2) inadequate or noncomparable data,

(3) failure to allow a gap of time for readjustment of the public to the change,

(4) failure to take account of other changes also affecting the situation,

(5) lack of control data to account for traffic trend,

(6) failure to rate according to exposure, and

(7) evaluation of a change as significant when in reality the change is within the realm of chance variation.

Before-after studies also present difficulties in finding enough suitable sites, in applying the resluts to other cases, and in finding the resources to accumulate "after" data.

Testing the significance of differences in mean values of parameters measured in "before" and "after" situations is done by a variety of methods. The test chosen is dependent on the particular study situation. The most used tests in the literature are the Chi-square distribution test, the Poisson distribution test, and a special variation of the student t-test for paired data (Refs 11, 21, 97, and 110).

Comparison and Individual Case Studies

A comparison study is a technique similar to the before-after study. Instead of evaluating a site before and after the proposed change, various sites with different facilities will be evaluated after the proposed change. This technique requires common denominators in each type of facility and they should be as homogeneous as possible. This method reduces the time span as required in the before-after study and still provides direct comparison of various sites. However, homogeneity between sites rarely exists in real world situations. Therefore, careful examination should be taken to select sites with similar characteristics before the comparison analysis.

An individual case study is a study of isolated locations. This method provides a more detailed analysis of the site. However, the peculiarity of each site provides little basis for comparison with other sites.

Performance Standard Studies

Performance standard studies (see Ref 11) involve only a simple comparison of calculated effects of an improvement to a standard. The method is applicable to situations in which adequate experience has been accumulated to set standards. These standards may be based on statistical analysis of previous experience, average or critical values, or even logic, if necessary.

SELECTION OF STUDY APPROACH

In developing guidelines for use of left-turn lanes, many different basic sets of conditions must be examined. It is also desirable to investigate many different variables within these basic subsets. The before-after study approach is impractical in this study due to the limited availability of time. Before-after and comparative parallel studies have already been conducted in many areas and can help provide information on possible accident reductions. The performance standard study approach is also undesirable due to difficulties in establishing standards for comparison, the large number of variables, and, in many respects, the purpose of the research study. Since it was desired to study operational as well as accident relationships, two study approaches were taken, regression analysis for accidents and comparison and individual case study for operations.

CHAPTER 4. REGRESSION ANALYSIS - DATA COLLECTION

Regression analysis can be used to investigate the relative importance of independent variables in determining accident statistics, to use these relationships for estimation of accident statistics, to describe the variability of the accident statistics, and to assist in identifying sites which have unusually high or low numbers of accidents or accident rates. The exact method of presenting variables which are found to be of importance. A computer-based statistical analysis package (Ref 28) was selected for the analysis in this approach.

IDENTIFICATION OF IMPORTANT VARIABLES

The identification of important variables was undertaken in an extensive review of related literature and consideration was given to how the data would be utilized. The literature expressed the data in many different forms and, in some cases, provided statistical parameters, such as means, standard deviations, significance, levels, etc., which aided in predicting the variability and relative importance of each variable. Transformations used in the studies also provided hints of possible transformations of data for the regression analysis.

Selection of data to be collected was based on the relative importance of the data and the degree of difficulty anticipated in collection of the data. Collection of data which would not generally be available or easily obtained by the traffic engineer was not considered practical. It was considered desirable to be able to separate accidents by location, type, severity, cause, etc. in order that accident characteristics might be more easily compared for different lane types and accident groupings. Site data were tabulated by block or sub-block in order that the sites could be examined at different levels of detail and in different combinations as necessary. The highest level of detail to be used in analysis of sites is the single mid-block, a short section with an intersection at each end. From this level of detail, sections of sites can be formed as desired for analysis. The flexibility allowed by the form of the data and in the regression analysis method allows latitude in examination of accident characteristics and their relationships to site characteristics.

DATA SOURCES

Data from several sources were combined to form the data base used in the analysis. These sources include field observations, accident records, and traffic count records, as well as other miscellaneous data sources.

Field data collection provided information on site geometrics, block numbers, lane types, speed limits, land uses, driveway locations, signals, section lengths, and other site characteristics. Accident data for each site were obtained from magnetic computer tapes maintained by the Office of Traffic Safety, Texas State Department of Highways and Public Transportation, (OTS, SDHPT). The tapes were accessed directly through the computer system of The University of Texas at Austin. Only the 1975 data were utilized since no identification codes for streets were used for previous years.

Volume data were obtained from SDHPT volume counts for cities throughout Texas, and volume counts were supplied by the cities surveyed. The counts represent weekday ADT's and were adjusted for the study year when necessary, based on traffic counts made in the immediate vicinity, volume growth trends, and city growth trends.

The cities participating in the study were also a source of recommendations for sites to be surveyed and for codes used in identifying accident locations. Other data were obtained from city maps and other published information.

SITE SELECTION

Cities in which data were collected were selected by location, size, and responses to a questionnaire survey (Ref 143) which supplied information on approximate percentages of left-turn lanes by type in each city, along with the number of years experience the respondents had had with each type of lane. In order to have a range of sites for the data collection process, tabulations of site characteristics (such as in Fig 4.1) were maintained; however, in each city the available sites were exhausted before time constraints made it necessary to be selective.

It was impossible to determine the number of sites necessary for the data analysis due to the unknown variability of accident rates and not knowing which rate would be most valuable, how the sites might have to be combined in the analysis, and how many and which variables might be important. It was therefore decided to obtain a representative sample for at least one lane type in hopes of determining variabilities of rates and identifying important variables. CTWLTML sites were chosen for this purpose due to the many questions surrounding their use. Data were also collected on a substantial number of COWLTML sites for comparison to the CTWLTML sites. Through this approach, it was most likely that relationships of accidents to site characteristics could be identified. Then, after a preliminary analysis, further field surveys could be made as necessary.

DATA COLLECTION PROCEDURE

A brief outline of the procedure for data collection and manipulation is presented in Fig 4.1. The procedure required the use of numerous computer programs to manipulate the data and numerous checks to verify that the data were manipulated properly. The following is a brief summary of the major points of the data collection and manipulation procedure.

Physical site data were obtained in the field by means of the survey form illustrated in Fig 4.2. This form allowed the flexibility necessary for coping with the many different site characteristics and still recording sufficient detail to allow the necessary information to be coded directly from the field sheet. Each block or portion of a block was coded by using three basic records (or card images): (1) a nondirectional record with information, such as the block number, speed limit, and distance from the central business district (CBD); (2) a directional card for direction 1, including lane widths, land use codes, driveways, drive information, a parking code, and number of lanes; and (3) a directional card for direction 2. Intersection data were recorded on a single card image.

The OTS accident record tapes were manipulated through the use of several computer programs to quickly reduce the amount of data which had to be stored and to assign identification codes to the accident records for matching with

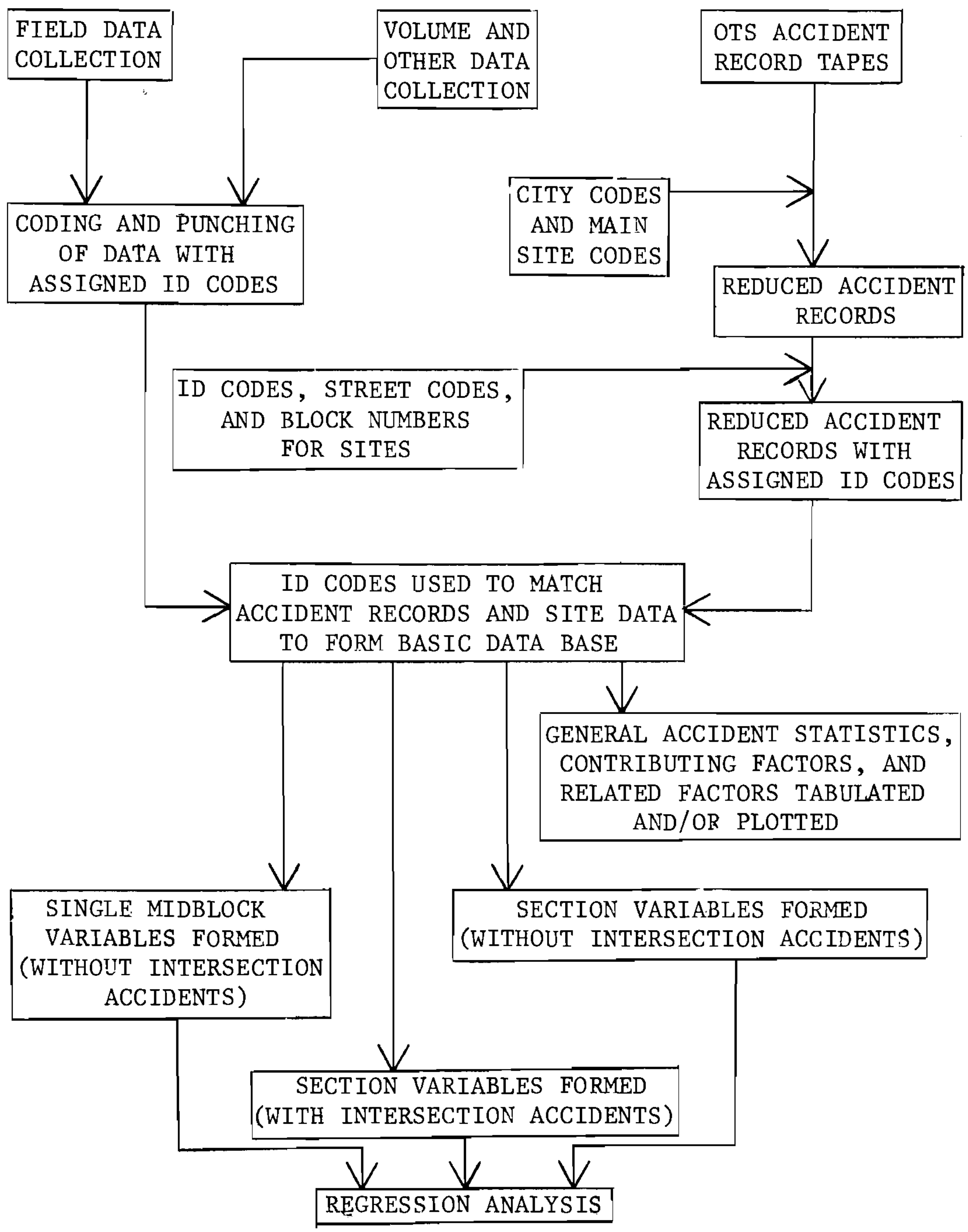


Fig 4.1. Data collection and manipulation process.

SECTION INVENTORY

CITY:____________ STREET:____________ TYPE:____________

SETTING:________ SECTION LENGTH:________ COMMENTS:____________

						L.T. LANE Chan. L.T.'s, Lengths, Width, Speed Limit	DIR. 1, No. Lanes, Width, Speed Limit	PARKING	STREETS Names, Drives, Block Nos.	LAND USE	%	DRIVER INFORMATION AND COMMENTS
DRIVER INFORMATION AND COMMENTS	%	LAND USE	STREETS Names, Drives, Block Nos.	PARKING	DIR. 2, No. Lanes, Width, Speed Limit	L.T. LANE Chan. L.T.'s, Lengths, Width, Speed Limit						

Fig 4.2. Field data collection form.

the site data. Each accident had at least two card images; there is no maximum number of card images which might be used to describe an accident.

The combined data base consists of site data card images followed by all the associated accident card images in a layered form. Computer programs were used to tabulate statistics and to form midblock and section variables used in analysis of the data. Appendix A lists several statistics for these variables.

DATA VALIDITY

As mentioned, checks of the data manipulation programs were made frequently to assure that the data used in the analysis were an accurate representation of the field data, accident records, and other data. However, other checks were also made to assure that the field data and accident data bases were unbiased and properly interpreted.

Engineers in each city surveyed were asked to recommend sites for the study which had field conditions at the time of the data collection which were essentially unchanged since late 1974. The recommendations of the surveyed engineers, along with their personal knowledge and observations, were used to select sites which could be confidently used in the study. The accuracy of the Austin accident records was verified through comparison of the OTS accident records with records obtained directly from the City of Austin Urban Transportation Department. Several of the surveyed city engineers expressed confidence in the accuracy of the records maintained by the Department of Public Safety. The interpretation of variables was verified through the OTS and by tabulations of certain variables which could be comparatively assessed.

REGRESSION ANALYSIS VARIABLES

The actual variables used in the regression analysis are tabulated in Table 4.1. Many of these variables are sufficiently explained in the table and may apply to midblocks or sections. However, the following paragraphs explain the meanings of some of the variables in more detail.

The identification codes for sites were assigned during the data collection and coding phases. The first two digits of the four digit code

TABLE 4.1. REGRESSION ANALYSIS VARIABLES

Variable Symbol Identification	Variable Code or Meaning
SITEID	Assigned 4 digit code for midblocks; combined site codes for sections (first site code . last site code).
XNTAM	No. accidents at a midblock location.
XNTA	No. accidents on a section.
XNLTAM	No. left-turn accidents at a midblock location.
XNLTA	No. left-turn accidents on a section.
XTAMMM	No. accidents/million vehicle miles at a midblock location.
XTAMM	No. accidents/million vehicle miles on a section.
XLTMMM	No. left-turn accidents/million vehicle miles at a midblock location.
XLTMM *	No. left-turn accidents/million vehicle miles on a section.
XAMM	No. accidents/mile (per year) at a midblock location.
XAM	No. accidents/mile (per year) on a section.
XLTMM *	No. left-turn accidents/mile (per year) at a midblock location.
XLTM	No. left-turn accidents/mile (per year) on a section.
SIM	Severity index; no. injury and fatal accidents/ total no. midblock accidents.
SI	Severity index; no. injury and fatal accidents/ total no. section accidents.
CRM	Critical accident rate at a midblock location (see test).
CR	Critical accident rate for a section (see text).
ADSM	Average damage scale for all accidents at a mid-block location (see text).
ADS	Average damage scale for all accidents on a section (see text).
VEHMI	Vehicle miles of travel/weekday.
XLTYP1	Dummy variable: 1 if CTWLTML, 0 if other.
XLTYP2	Dummy variable: 1 if flush COWLTML, 0 if other.
XLTYP3	Dummy variable: 1 if raised COWLTML, 0 if other.
SECLEN	Block or section length in miles (nearest .01 mile).
DCBD	Distance (midblock) or average distance (sections) in miles from a selected CBD center (nearest .1 mile).
CISZ	City population (est.).
DIOSZ	DCBD/CISZ
THRUSL	Speed limit for through lanes in miles/hour.
XLTSL	Dummy Variable: 1 if posted left-turn lane speed, 0 if none posted (all posted left-turn lanes speeds were 20 miles/hour).
XLTWI	Left-turn lane width in feet (nearest .1 foot).
XTLWI	Sum of through lane widths in feet (nearest .1 foot).
XNTHL	No. through lanes.
ATHWI	Average width of through lanes; XTLWI/XNTHL.
XCHLT	No. channelized left-turn bays.
AS1	Dummy variable (Midblock): 1 if direction 1 approaches signal, 0 if not approach to signal.
AS2	Dummy variable (Midblock): 1 if direction 2 approaches signal, 0 if not approach to signal
XNAS1	Number of approaches to signals on section.
XNSIG	Number of signals on section.
PKG1	Dummy Variable: 1 if parking in direction 1, 0 if no parking.
PKG2	Dummy Variable: 1 if parking in direction 2, 0 if no parking.
XCTWT	No. transitions from CTWLTML to a continuous one-way left-turn median lane.
TWADT	Two-Way weekday ADT (weighted by section lengths).
XLEG1	Dummy variable (Midblock): 1 if direction 1 approaches 3-leg intersection, 0 if other.
XLEG2	Dummy variable (Midblock): 1 if direction 2 approaches 3-leg intersection, 0 if other.
XN3L	No. 3-leg intersections on section.
XN4L	No. 4-leg intersections on section.
TNDR	Total no. driveways.
TNDRM	No. driveways/mile, TNDR/SECLEN.
PAC	Percent commercial land use.
XNAC	No. driveways to commercial land use.
XNACM	No. driveways to commercial land use/mile, XNAC/SECLEN.
PSER	Percent office and service land uses.
XNSER	No. driveways to office and service land uses.
XNSERM	No. driveways to office and service land uses/ mile, XNSER/SECLEN.
PPUB	Percent public land use.
XNPUB	No. driveways to public land use.
XNPUBM	No. driveways to public land use/mile, XNPUB/ SECLEN
PRES	Percent residential land use.
XNRES	No. driveways to residential lane use.
XNRESM	No. driveways to residential land use/mile, XNRES/SECLEN.
PVAC	Percent vacant land use.
XNSPM	No. signals/mile, XNSIG/SECLEN.
PPLT	Percent of signals with protected left-turn phases for main roadway traffic.

*The XLTMM symbol identification for sections and midblocks is the same in this case since section and midblock analyses are run separately.

identify a particular site. The second two digits begin at 01 and continue consecutively to the end of the site. For convenience each site begins and ends with an intersection and all intersections are odd in number; midblocks are even in number. Dummy intersections are used to separate a single midblock when it is necessary to separate two block numbers on a single midblock. The site identification for a section is assigned the first intersection or midblock code followed by a decimal and then the ending intersection or midblock code.

The numbers of accidents and accident rates were calculated by summation of accidents and by formulas which can be easily found in many references. Left-turn accidents were identified by the vehicle movements coded on the accident records. Intersection accidents were omitted from all the midblock rates. Sections were formed with and without the intersection accidents in order to provide a better means of comparison of the site types.

Each accident on the OTS tapes is identified by a five digit city code. Accident locations within the city are identified by a five digit primary street code and/or a five-digit secondary street code and/or a block number to the nearest one hundred block. Accidents occurring at intersections can be located by only the two street codes, and accidents not at intersections can be located by only one street code and a block number. In addition, a code is supplied identifying an accident as intersection, intersection-related, driveway, or nonintersection. In some cases, however, two street codes and a block number are supplied. Accidents of this type which were identified as intersection accidents were assigned to the intersection location if applicable. If the accident was coded as other than intersection, a manual inspection was required to properly determine where the accident would be assigned. For this reason, and the belief than many intersection-related accidents might be related to the type of left-turn lane, accidents coded as intersection related were included in midblock locations.

The severity index provides a rough comparison of sites in terms of percent injury and fatal accidents. Fatal injuries were very rare; of approximately 2500 accidents used in the analysis of sections, less than 0.4 percent involved fatal injuries.

The critical rate (see Ref 10) is calculated to compare the accident rate at a specific location to rates at other locations, based on the average rate of all the locations. If the accident rate exceeds the critical rate, the deviation is probably not due to chance and further study of the site is recommended. The critical rate can be used in the regression analysis and through direct comparison with the accident rate (expressed as accidents per million vehicle-miles) to help identify extreme conditions. The critical accident is calculated for a section as

$$R_c = R_a + k \quad \frac{R_a}{M} + \frac{1}{2M}$$

where

R_c = critical accident rate for the section,

R_a = average accident rate for all sections in the group in accidents per million vehicle-miles,

M = millions of vehicle-miles for the section, and

k = probability constant (1.5 was used, as recommended in Ref 10).

From the average damage scale, a value is assigned to each vehicle in an accident as a relative comparison of property damage. The scale (ranging from one to seven) is very subjective and therefore probably very difficult to relate to site variables; however, the average damage scale for a site may provide some insight into conditions which increase property damages.

The "vehicle miles of travel" was calculated on a daily basis by multiplying the weekday ADT times the section length. Since ADT values were estimated for each block, the vehicle miles for each block were calculated and summed over the total length of the section when several blocks were combined.

Several dummy variables were used in the analysis as simple tests of whether or not the existence of a posted speed limit in the left-turn lane, the existence of signals on the ends of the midblock sites, the existence of parking, or the existence of three-leg intersections could account for differences between sites.

The two-way weekday ADT volumes were estimated for the 1975 base year as previously described. The ADT volumes for midblocks where counts were not available were estimated from counts at other points along the site.

As a whole, the data collected and the variables formed for the data analysis provide a great deal of valuable information in a concentrated and flexible form for identifying many accident characteristics and relationships to site variables.

SUMMARY

The data collection effort combined several sources of data through a careful manipulation and verification process (Ref 64). The basic data base could then be used to tabulate accident and site statistics, to facilitate the combining of sites to various levels of detail, and to calculate variables for use in the regression analysis.

CHAPTER 5. ACCIDENT STUDY DATA ANALYSIS

DESCRIPTION OF DATA BASE

A description of the data collected serves two purposes: (1) to provide insight into the characteristics of the sites and accidents which are being used in the analysis and (2) to describe existing field applications of various left-turn-lane types. Means and standard deviations of the variables used in the analysis are given in the appendix.

Figures 5.1 and 5.2 show miles of CTWLTML and raised COWLTML sites used in the analysis in categories of ADT range, speed limit, and number of through lanes. Figure 5.1 illustrates that CTWLTML's are primarily located on roadways with under 25,000 ADT, under 50 mph speed limits, and four lanes. Figure 5.2 illustrates that the sections of raised COWLTML's surveyed are generally under 15,000 or over 25,000 ADT, have speed limits under 50 mph, and have six through lanes on higher volume sections. The six-lane section with a CTWLTML is a single block with few left-turns and pedestrians and the CTWLTML serves primarily as a median divider.

Figures 5.3, 5.4, 5.5, and 5.6 compare CTWLTML and raised COWLTML accidents in term of hour of occurence, number of vehicles involved, severity, and location, respectively. Figures 5.3 and 5.4 show that the two types of lanes follow very similar and common patterns for accidents by hour of occcurrence and number of vehicles involved. The comparison of lane types by severity of accidents shows that there may be a slight difference between the lane types; however, the difference is quite possibly due to differences in site characteristics. Figure 5.6 shows the most striking difference between CTWLTML's and raised COWLTML's in terms of general accident statistics. Approximately 75 percent of the accidents on raised COWLTML sections were at intersection or intersection-related locations, compared to 55 percent on CTWLTML sections. Only 6 percent of the accidents on raised COWLTML sections were related to driveway access while driveway access accidents on the CTWLTML sections were 14 percent of the total accidents.

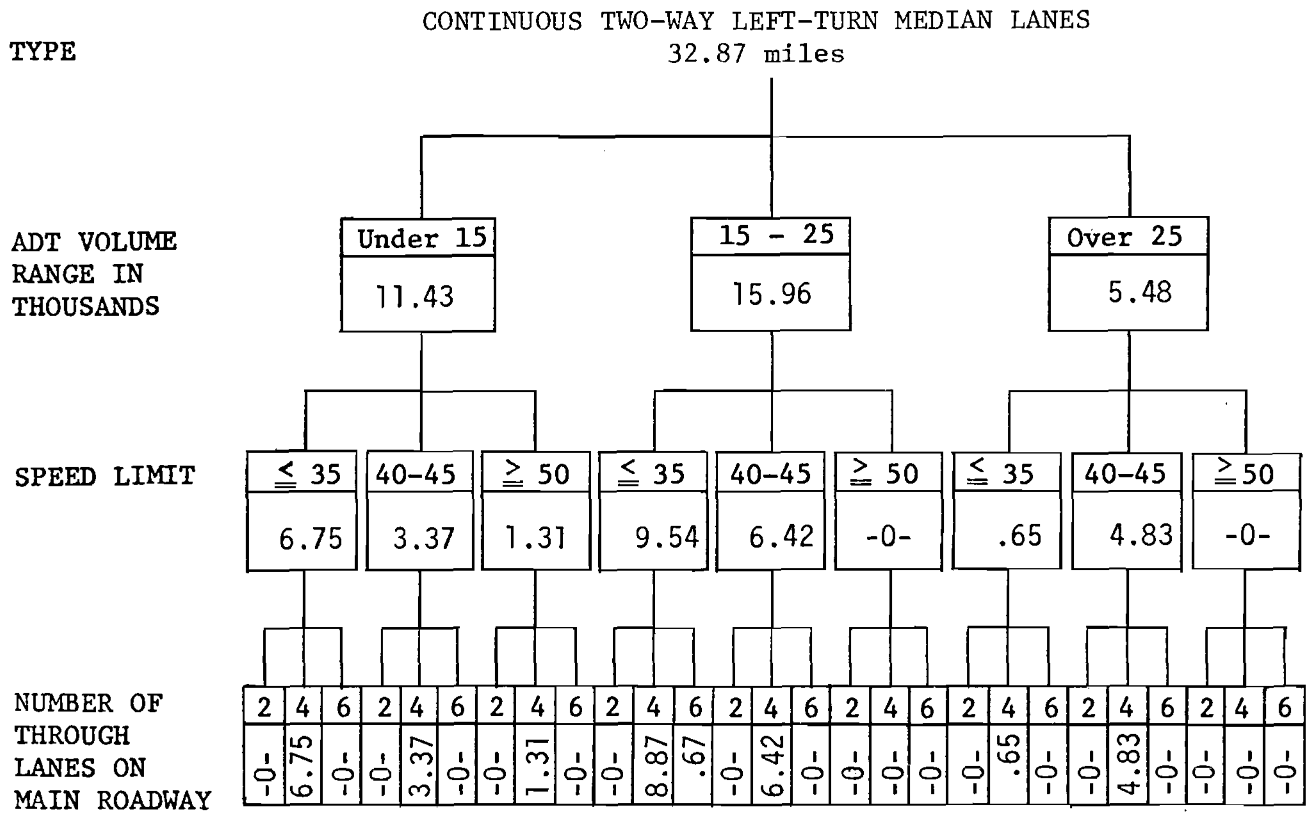


Fig 5.1. Miles of CTWLTML's by section categories.

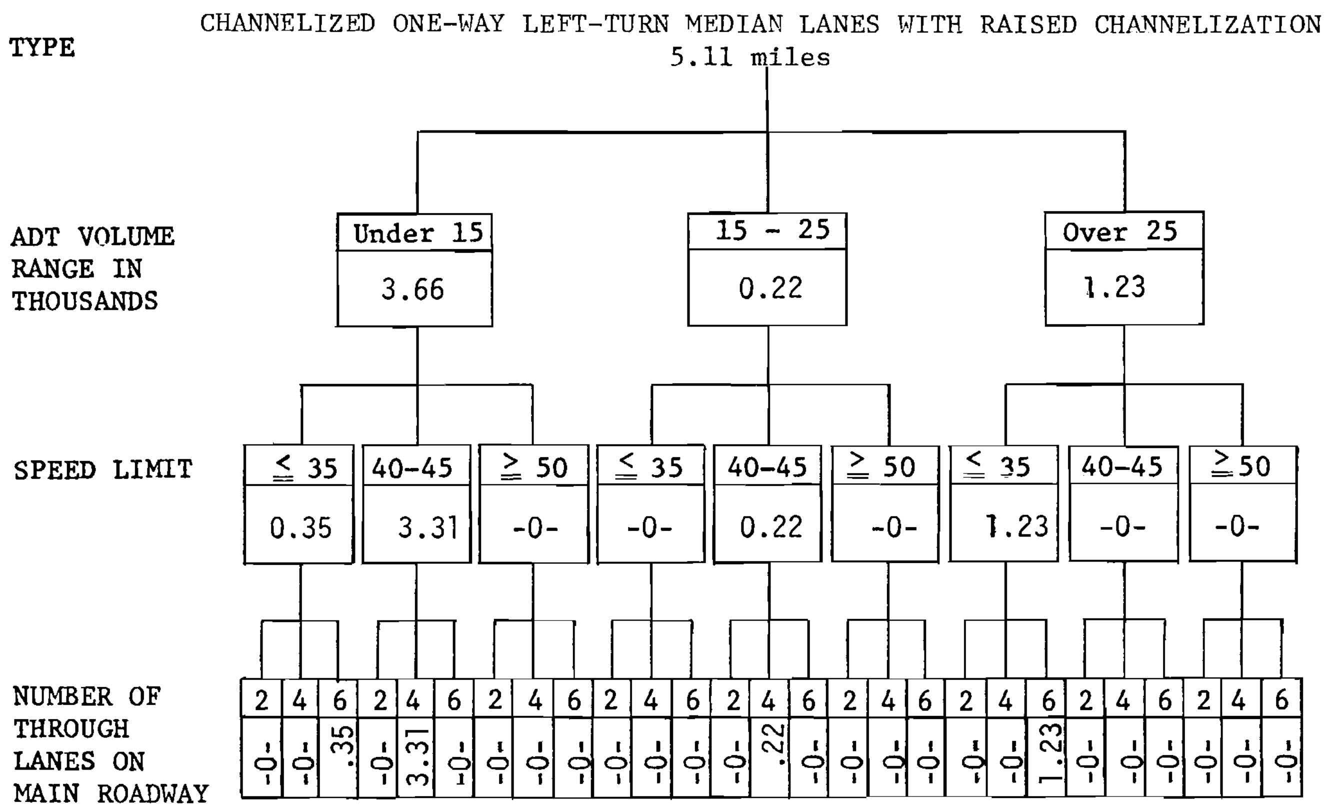


Fig 5.2. Miles of raised COWLTML's by section categories.

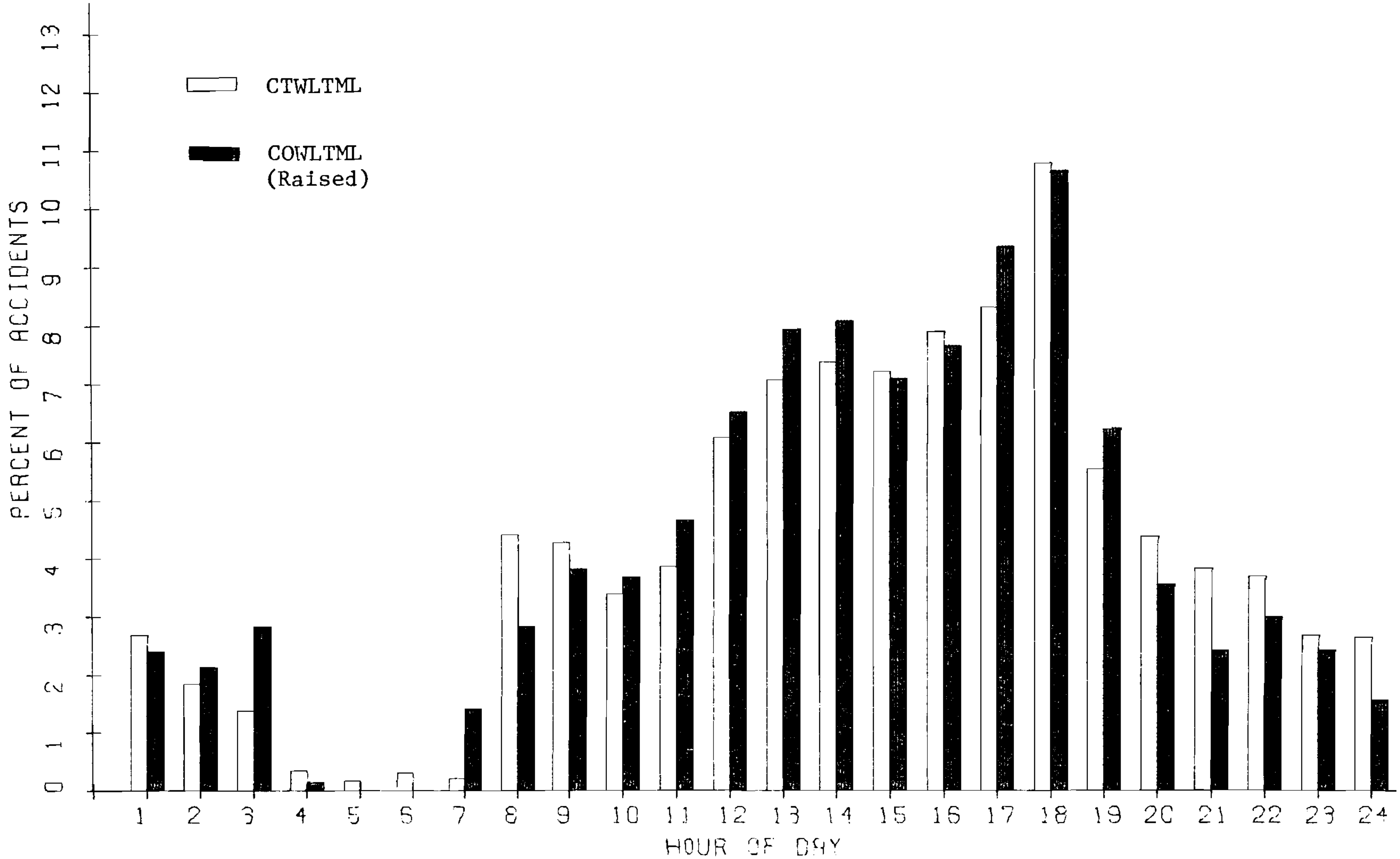


Fig 5.3. Percent accidents by hour of day.

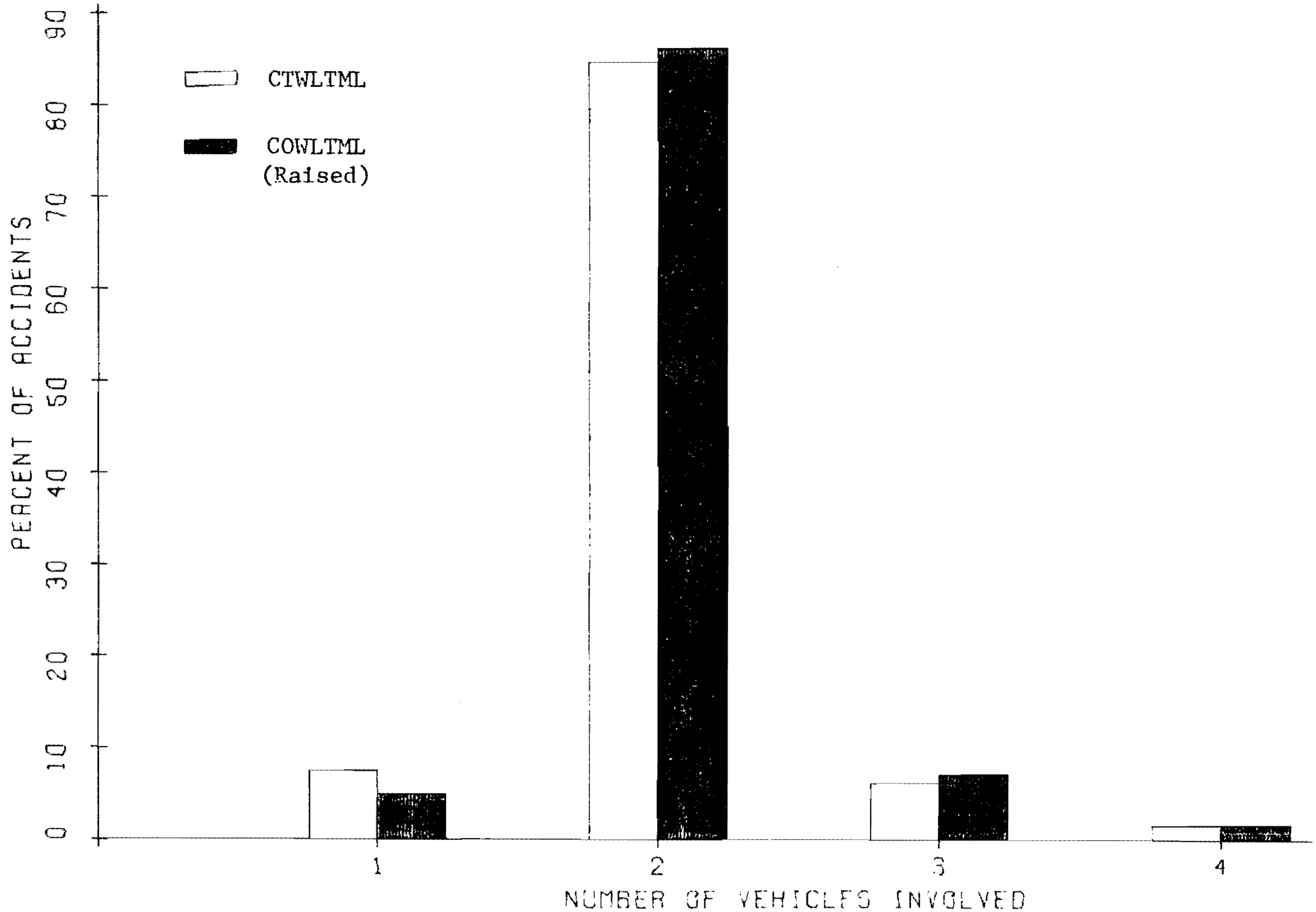


Fig 5.4. Percent accidents by number of vehicles involved.

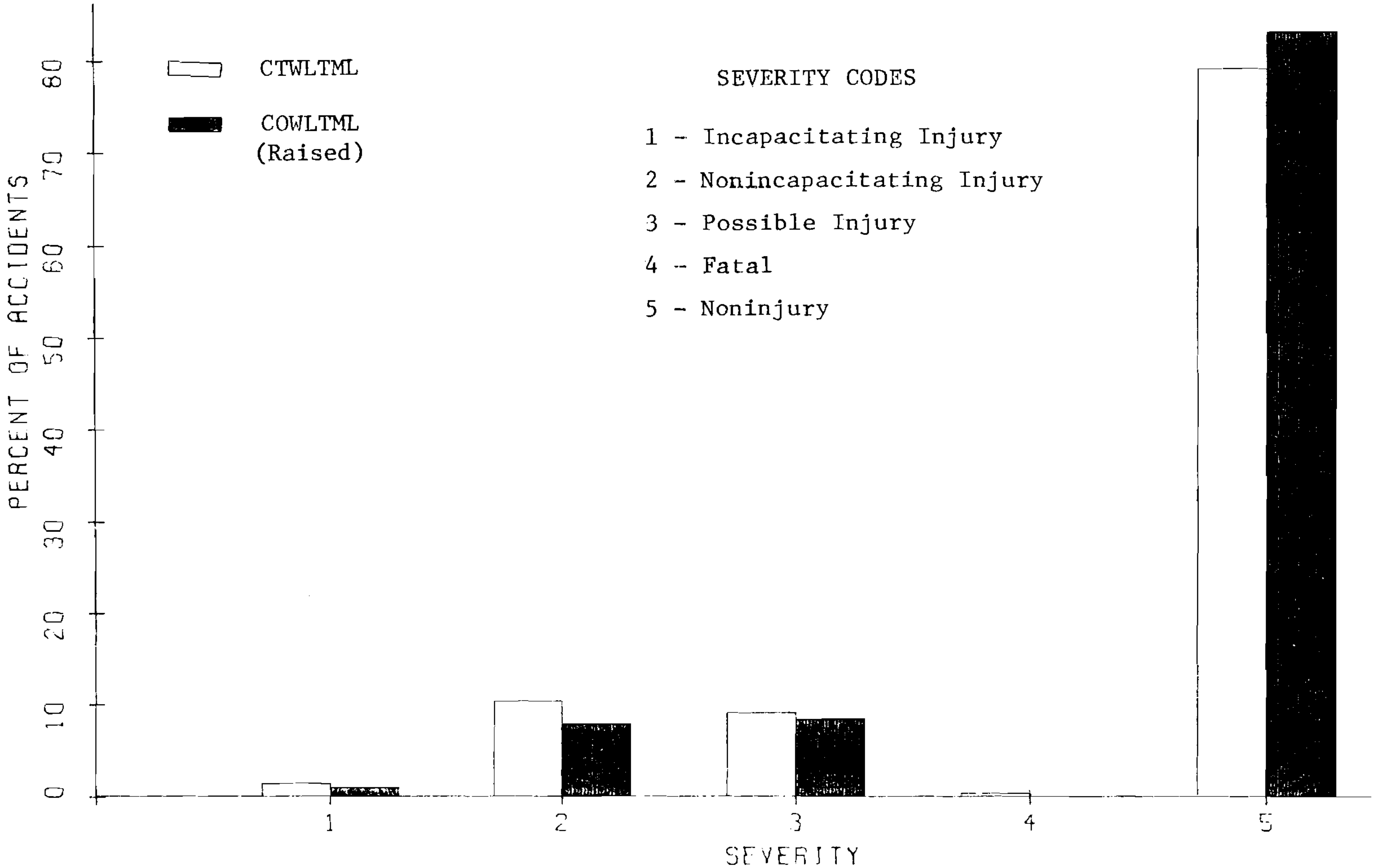


Fig 5.5. Percent accidents by severity code.

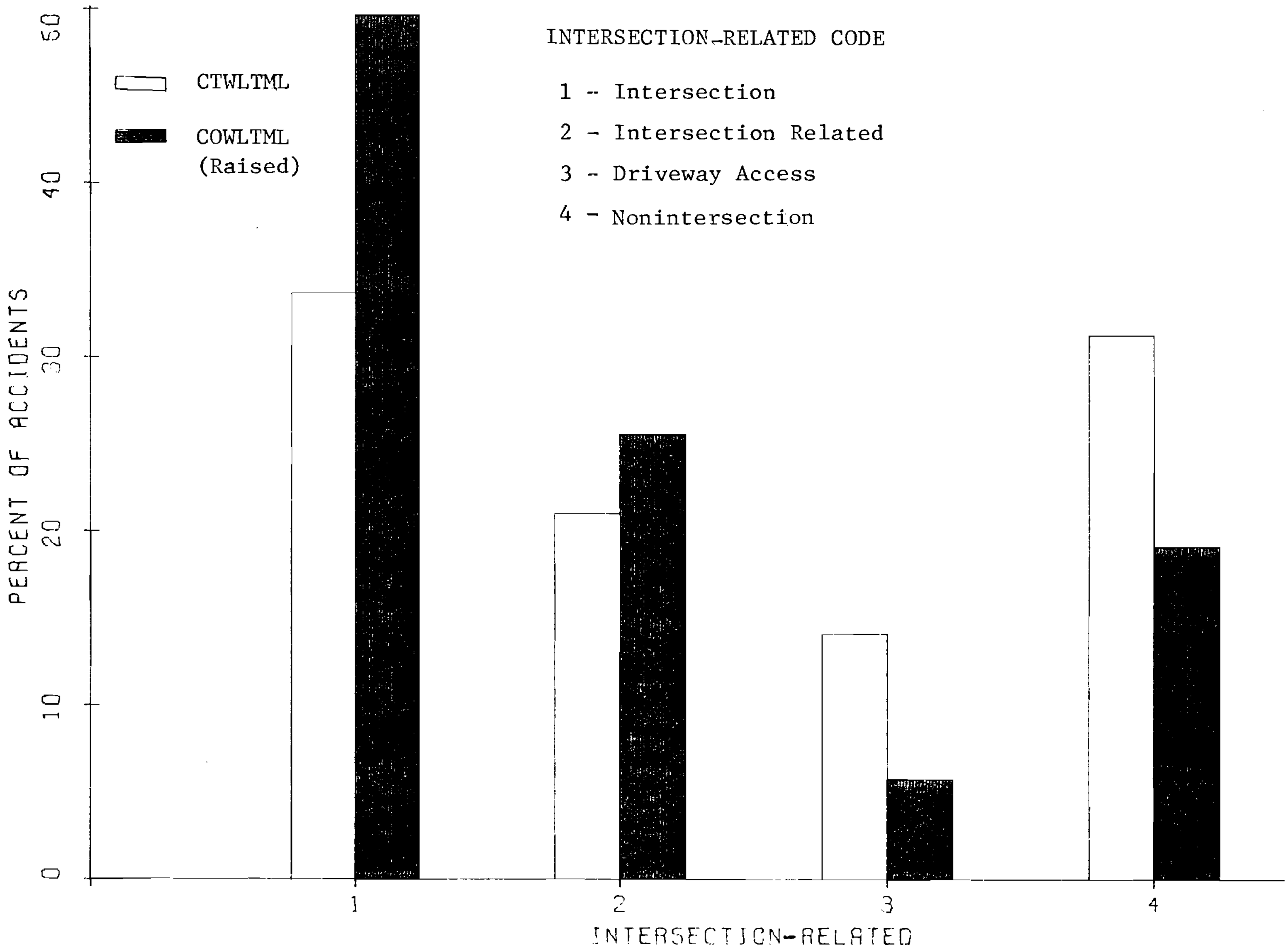


Fig 5.6. Percent accidents by intersection-related code.

CONTRIBUTING AND RELATED FACTORS

Factors contributing and related to accidents were tabulated in order to identify general accident types, causes, and vehicle movements. Due to differences in the number of codes which may apply to a single accident, the tabulations do not necessarily reflect the numbers of accidents which occurred, and the number of factors coded as contributing or related to accidents may vary. It should be realized that comparisons of CTWLTML's and raised COWLTML's in the following discussions on contributing and related factors are made primarily on a percentage basis and not a rate basis (i.e., land uses, driveway frequencies, left-turn volumes, etc. are not taken into account).

Contributing Factors

Contributing factors as related to various accident types are presented in Tables 5.1, 5.2, 5.3, and 5.4. In each of these tables, all accidents included in accident types H through K have been previously accounted for in accident types A through F . Accident types N and O are also accounted for in other accident types. The tables present many interesting relationships; some of the more important of these relationships are summarized below.

Tables 5.1 and 5.2 present midblock accident tabulations at CTWLTML and raised COWLTML sites, respectively. In both cases the major contributing factors were unsafe speeding, failing to yield right-of-way, and following too closely. For CTWLTML sites unsafe speeding and failure to yield right-of-way accounted for 56 percent of the cases involving two motor vehicles, compared to 24 percent for raised COWLTML sites. On raised COWLTML sites, for 42 percent of two-vehicle cases, following too closely was cited as a contributing factor, compared to only 14 percent on CTWLTML sites. The unsafe speeding violation is related to same direction accidents for both types of left-turn lanes; the raised COWLTML sites have a larger percentage of same direction cases, especially sideswipe, than the CTWLTML sites. CTWLTML sites have a larger percentage of angle and opposite direction accidents, which appear to be due to failing to yield right-of-way in most cases.

TABLE 5.1. ACCIDENT TYPES AND CONTRIBUTING FACTORS AT CTWLTML MIDBLOCK LOCATIONS

ACCIDENT TYPE	CONTRIBUTING FACTORS* NUMBER OF CASES															
	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.	TOTAL
A TWO MOTOR VEH. APPROACHING AT AN ANGLE	4	5	161	2	2	8	3	0	2	0	0	2	0	8	2	199
B TWO MOTOR VEH. GOING SAME DIR. - REAR END	2	134	1	0	0	0	0	0	48	0	0	0	0	5	11	201
C TWO MOTOR VEH. GOING SAME DIR. - SIDESWIPE	4	7	0	0	0	0	0	0	0	1	0	0	0	3	156	171
D TWO MOTOR VEH. GOING SAME DIR. - OTHER	8	312	2	0	1	2	0	37	123	5	0	10	0	20	16	536
E TWO MOTOR VEH. GOING OPPOSITE DIR.	3	8	69	0	0	1	1	0	0	0	0	23	0	4	16	125
F TWO MOTOR VEH. - OTHER THAN A.-E.	0	1	19	0	0	0	0	0	0	0	0	20	0	1	1	42
G TOTAL	21	467	252	2	3	11	4	37	173	6	0	55	0	41	202	1274
H TWO MOTOR VEH. - BOTH LEFT TURN	0	0	6	0	0	0	0	3	0	0	0	0	0	0	1	10
I TWO MOTOR VEH. - ONE LEFT TURN	5	4	181	0	1	1	4	11	3	3	0	0	0	7	2	222
J TWO MOTOR VEH. - LEFT TURN (H.+I.)	5	4	187	0	1	1	4	14	3	3	0	0	0	7	3	232
K TWO MOTOR VEH. - RIGHT TURN	2	18	45	1	1	11	1	23	12	1	0	1	0	4	3	123
L OTHER THAN MOTOR WITH MOTOR VEH. - LEFT TURN	2	1	2	0	0	0	0	0	0	0	0	0	2	0	1	8
M OTHER THAN MOTOR WITH MOTOR VEH. - TOTAL	14	52	2	0	0	0	0	0	1	0	0	4	3	30	10	116
N PEDESTRIAN OR PEDACYCLIST	1	1	2	0	0	0	0	0	0	0	0	0	3	3	0	10
O FIXED OBJECT	10	33	0	0	0	0	0	0	0	0	0	0	0	18	3	64

* CONTRIBUTING FACTORS

1. SPEEDING, LIMIT
2. SPEEDING, UNSAFE
3. FAILED TO YIELD RIGHT OF WAY
4. DISREGARD STOP SIGN OR LIGHT
5. DISREGARD STOP AND GO SIGNAL
6. IMPROPER TURN, WIDE RIGHT
7. IMPROPER TURN, CUT CORNER ON LEFT
8. IMPROPER TURN, WRONG LANE
9. FOLLOWING TOOCLOSELY
10. PASSING
11. NO SIGNAL OR WRONG SIGNAL OF INTENT
12. IMPROPER START FROM PARKED POSITION
13. FAIL TO YIELD ROW TO PEDESTRIAN
14. UNDER INFLUENCE OF ALCOHOL OR DRUGS
15. OTHER

TABLE 5.2. ACCIDENT TYPES AND CONTRIBUTING FACTORS AT RAISED COWLTML MIDBLOCK LOCATIONS

ACCIDENT TYPE	CONTRIBUTING FACTORS* NUMBER OF CASES															
	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.	TOTAL
A TWO MOTOR VEH. APPROACHING AT AN ANGLE	2	0	17	0	1	1	0	0	0	0	0	1	0	0	0	22
B TWO MOTOR VEH. GOING SAME DIR. - REAR END	1	2	0	0	0	0	0	0	14	0	0	0	0	2	0	19
C TWO MOTOR VEH. GOING SAME DIR. - SIDESWIPE	0	1	0	0	0	0	0	0	0	1	0	0	0	1	31	34
D TWO MOTOR VEH. GOING SAME DIR. - OTHER	1	19	0	0	0	0	0	3	66	0	1	3	0	3	3	99
E TWO MOTOR VEH. GOING OPPOSITE DIR.	0	1	5	0	0	0	0	0	0	0	0	3	0	0	4	13
F TWO MOTOR VEH. - OTHER THAN A.-E.	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	2
G TOTAL	4	23	23	0	1	1	0	3	80	1	1	8	0	6	38	189
H TWO MOTOR VEH. - BOTH LEFT TURN	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
I TWO MOTOR VEH. - ONE LEFT TURN	1	1	16	0	1	0	0	0	2	0	0	0	0	0	1	22
J TWO MOTOR VEH. - LEFT TURN (H.+I.)	1	1	16	0	1	0	0	0	2	0	0	0	0	0	1	22
K TWO MOTOR VEH. - RIGHT TURN	1	0	4	0	0	1	0	3	6	0	0	1	0	0	0	16
L OTHER THAN MOTOR WITH MOTOR VEH. - LEFT TURN	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
M OTHER THAN MOTOR WITH MOTOR VEH. - TOTAL	6	6	0	0	0	0	0	0	0	0	0	0	0	1	0	13
N PEDESTRIAN OR PEDACYCLIST	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
O FIXED OBJECT	2	5	0	0	0	0	0	0	0	0	0	0	0	1	0	8

* CONTRIBUTING FACTORS

1. SPEEDING, LIMIT
2. SPEEDING, UNSAFE
3. FAILED TO YIELD RIGHT OF WAY
4. DISREGARD STOP SIGN OR LIGHT
5. DISREGARD STOP AND GO SIGNAL
6. IMPROPER TURN, WIDE RIGHT
7. IMPROPER TURN, CUT CORNER ON LEFT
8. IMPROPER TURN, WRONG LANE
9. FOLLOWING TOOCLOSELY
10. PASSING
11. NO SIGNAL OR WRONG SIGNAL OF INTENT
12. IMPROPER START FROM PARKED POSITION
13. FAIL TO YIELD ROW TO PEDESTRIAN
14. UNDER INFLUENCE OF ALCOHOL OR DRUGS
15. OTHER

TABLE 5.3. ACCIDENT TYPES AND CONTRIBUTING FACTORS AT SIGNALIZED INTERSECTION LOCATIONS

ACCIDENT TYPE	CONTRIBUTING FACTORS* NUMBER OF CASES															
	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.	TOTAL
A TWO MOTOR VEH. APPROACHING AT AN ANGLE	3	4	54	7	271	6	2	0	0	0	0	2	0	9	2	360
B TWO MOTOR VEH. GOING SAME DIR. - REAR END	0	5	0	0	0	0	0	0	2	0	0	0	0	0	0	7
C TWO MOTOR VEH. GOING SAME DIR. - SIDESWIPE	0	1	0	0	0	0	0	0	0	0	0	0	0	0	10	11
D TWO MOTOR VEH. GOING SAME DIR. - OTHER	3	71	0	0	0	1	1	43	54	1	1	7	0	1	10	193
E TWO MOTOR VEH. GOING OPPOSITE DIR.	6	2	199	1	30	2	1	1	0	1	0	5	0	6	3	257
F TWO MOTOR VEH. - OTHER THAN A.-E.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
G TOTAL	12	83	253	8	301	9	4	44	56	2	1	14	0	16	25	828
H TWO MOTOR VEH. - BOTH LEFT TURN	0	1	1	0	3	0	0	2	2	0	0	0	0	0	3	12
I TWO MOTOR VEH. - ONE LEFT TURN	6	6	202	2	58	3	4	23	3	1	0	0	0	7	6	321
J TWO MOTOR VEH. - LEFT TURN (H.+I.)	6	7	203	2	61	3	4	25	5	1	0	0	0	7	9	333
K TWO MOTOR VEH. - RIGHT TURN	1	7	24	0	7	9	0	19	1	0	1	0	0	1	2	72
L OTHER THAN MOTOR WITH MOTOR VEH. - LEFT TURN	0	0	5	0	0	0	0	0	0	0	0	0	2	0	0	7
M OTHER THAN MOTOR WITH MOTOR VEH. - TOTAL	1	0	5	0	0	0	0	0	0	0	0	0	5	1	0	12
N PEDESTRIAN OR PEDACYCLIST	0	0	5	0	0	0	0	0	0	0	0	0	5	0	0	10
O FIXED OBJECT	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	2

* CONTRIBUTING FACTORS

1. SPEEDING, LIMIT
2. SPEEDING, UNSAFE
3. FAILED TO YIELD RIGHT OF WAY
4. DISREGARD STOP SIGN OR LIGHT
5. DISREGARD STOP AND GO SIGNAL
6. IMPROPER TURN, WIDE RIGHT
7. IMPROPER TURN, CUT CORNER ON LEFT
8. IMPROPER TURN, WRONG LANE
9. FOLLOWING TOO CLOSELY
10. PASSING
11. NO SIGNAL OR WRONG SIGNAL OF INTENT
12. IMPROPER START FROM PARKED POSITION
13. FAIL TO YIELD ROW TO PEDESTRIAN
14. UNDER INFLUENCE OF ALCOHOL OR DRUGS
15. OTHER

TABLE 5.4. ACCIDENT TYPES AND CONTRIBUTING FACTORS AT UNSIGNALIZED INTERSECTION LOCATIONS

ACCIDENT TYPE	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.	TOTAL
	CONTRIBUTING FACTORS * NUMBER OF CASES															
A TWO MOTOR VEH. APPROACHING AT AN ANGLE	5	1	192	12	3	2	3	0	0	0	0	0	0	4	2	224
B TWO MOTOR VEH. GOING SAME DIR. - REAR END	0	7	0	0	0	0	0	0	6	0	0	0	0	0	0	13
C TWO MOTOR VEH. GOING SAME DIR. - SIDESWIPE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	11	11
D TWO MOTOR VEH. GOING SAME DIR. - OTHER	1	20	0	0	0	1	0	21	20	4	0	1	0	2	2	72
E TWO MOTOR VEH. GOING OPPOSITE DIR.	2	2	60	0	0	0	3	1	0	1	0	3	0	4	1	77
F TWO MOTOR VEH. - OTHER THAN A.-E.	0	0	1	0	0	0	0	0	0	0	0	1	0	1	0	3
G TOTAL	8	30	253	12	3	3	6	22	26	5	0	5	0	11	16	400
H TWO MOTOR VEH. - BOTH LEFT TURN	0	4	8	0	0	0	2	0	0	0	0	0	0	2	0	16
I TWO MOTOR VEH. - ONE LEFT TURN	4	3	143	2	0	0	4	10	0	2	0	1	0	6	3	178
J TWO MOTOR VEH. - LEFT TURN (H.+I.)	4	7	151	2	0	0	6	10	0	2	0	1	0	8	3	194
K TWO MOTOR VEH. - RIGHT TURN	1	5	23	2	0	3	0	12	5	2	0	0	0	2	1	56
L OTHER THAN MOTOR WITH MOTOR VEH. - LEFT TURN	0	0	2	0	0	0	0	0	0	0	0	0	1	0	0	3
M OTHER THAN MOTOR WITH MOTOR VEH. - TOTAL	0	1	4	0	0	0	0	0	0	0	0	0	1	0	0	6
N PEDESTRIAN OR PEDACYCLIST	0	0	3	0	0	0	0	0	0	0	0	0	1	0	0	4
O FIXED OBJECT	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1

* CONTRIBUTING FACTORS

1. SPEEDING, LIMIT
2. SPEEDING, UNSAFE
3. FAILED TO YIELD RIGHT OF WAY
4. DISREGARD STOP SIGN OR LIGHT
5. DISREGARD STOP AND GO SIGNAL
6. IMPROPER TURN, WIDE RIGHT
7. IMPROPER TURN, CUT CORNER ON LEFT
8. IMPROPER TURN, WRONG LANE
9. FOLLOWING TOO CLOSELY
10. PASSING
11. NO SIGNAL OR WRONG SIGNAL OF INTENT
12. IMPROPER START FROM PARKED POSITION
13. FAIL TO YIELD ROW TO PEDESTRIAN
14. UNDER INFLUENCE OF ALCOHOL OR DRUGS
15. OTHER

Left-turn accidents, which are also strongly related to failing to yield right-of-way, are 18 percent of the two-vehicle cases in the CTWLTML tabulation and 12 percent of the cases in the raised COWLTML tabulation. Improper turns were cited as contributing factors much more frequently at CTWLTML sites. Accidents involving pedestrians, which account for less than one percent of all the cases, were cited only on the CTWLTML sites.

The above relationships illustrate the effects of greater freedom of movement allowed by CTWLTML's to provide continuous access to abutting property. Tables 5.3 and 5.4 illustrate how accident types and contributing factors at signalized and unsignalized intersections differ from midblock cases and illustrate the differences in patterns between signalized and unsignalized intersections where median turn lanes are provided. However, it should be noted that some unsignalized intersections on raised COWLTML sections may not be provided with left-turn bays.

Related Factors

Factors related to accidents on both CTWLTML and raised COWLTML sites are presented in Tables 5.5, 5.6, and 5.7 and are tabulated as number of cases and percents. These factors are descriptors of vehicle movements related to accidents. As noted in the tables, driveway factors are given priority over other codes. If more than one factor were applicable in any accident, the one most pertinent to the accident was coded.

Table 5.5 summarizes factors related to accidents at midblock locations. There are several notable differences between the CTWLTML and raised COWLTML sites. While there is only a small difference in the percent of cases involving vehicles entering driveways, the percent of cases involving vehicles leaving driveways on CTWLTML sites is over twice that of those on raised COWLTML sites. Although there is a small compensation in this conflict zone where other vehicles are entering the road, the use of CTWLTML's as acceleration lanes would appear to increase the percent of driveway related accidents; however, percents of left-turn accidents from sites with land uses typical of CTWLTML sites may make such an assumption open to question. It is important to note that the category of vehicles slowing or stopping to make a left turn is a small category for both types of sites.

TABLE 5.5. FACTORS RELATED TO ACCIDENTS AT MIDBLOCK LOCATIONS

FACTOR DESCRIPTION	CTW*		COW** WITH CURB	
	NO. CASES	PERCENT OF COLUMN	NO. CASES	PERCENT OF COLUMN
VEH. PASSING ON LEFT	4	.3	0	0.0
VEH. CHANGING LANES	156	11.1	28	13.1
ONE VEH. ENTERING DRIVEWAY***	115	8.2	15	7.0
ONE VEH. LEAVING DRIVEWAY***	175	12.4	13	6.1
SWERVE - REASON NOT SPECIFIED	6	.4	1	.5
SWERVE - PEDESTRIAN, CYCLE, ETC.	0	0.0	0	0.0
SWERVE - OTHER VEH. STOPPED OR SLOWING	8	.6	1	.5
SWERVE - OTHER VEH. ENTERED ROAD	10	.7	3	1.4
SLOW OR STOP - REASON NOT SPECIFIED	50	3.5	10	4.7
SLOW OR STOP - TRAFFIC CONTROL - OFFICER	255	18.1	55	25.7
SLOW OR STOP - PEDESTRIAN, CYCLE, ETC.	6	.4	0	0.0
SLOW OR STOP - OTHER VEH. SLOW OR STOP	227	16.1	27	12.6
SLOW OR STOP - OTHER VEH. ENTERED ROAD	3	.2	0	0.0
SLOW OR STOP - TO MAKE RIGHT TURN	9	.6	5	2.3
SLOW OR STOP - TO MAKE LEFT TURN	29	2.1	9	4.2
NO CODE GIVEN WAS APPLICABLE	339	24.1	40	18.7
OTHER CODE GIVEN	17	1.2	7	3.3
TOTAL	1409	100.0	214	100.0

*CTW - CONTINUOUS TWO-WAY LEFT-TURN MEDIAN LANE
**COW - CHANNELIZED ONE-WAY LEFT-TURN MEDIAN LANE
***HAS PRIORITY OVER OTHER CODES

TABLE 5.6. FACTORS RELATED TO ACCIDENTS AT SIGNALIZED INTERSECTION LOCATIONS

FACTOR DESCRIPTION	CTW*		COW** WITH CURB	
	NO. CASES	PERCENT OF COLUMN	NO. CASES	PERCENT OF COLUMN
VEH. PASSING ON LEFT	0	0.0	0	0.0
VEH. CHANGING LANES	10	1.4	0	0.0
ONE VEH. ENTERING DRIVEWAY***	5	.7	0	0.0
ONE VEH. LEAVING DRIVEWAY***	4	.6	0	0.0
SWERVE - REASON NOT SPECIFIED	0	0.0	1	1.6
SWERVE - PEDESTRIAN, CYCLE, ETC.	0	0.0	0	0.0
SWERVE - OTHER VEH. STOPPED OR SLOWING	0	0.0	0	0.0
SWERVE - OTHER VEH. ENTERED ROAD	2	.3	1	1.6
SLOW OR STOP - REASON NOT SPECIFIED	17	2.4	0	0.0
SLOW OR STOP - TRAFFIC CONTROL - OFFICER	101	14.0	1	1.6
SLOW OR STOP - PEDESTRIAN, CYCLE, ETC.	0	0.0	0	0.0
SLOW OR STOP - OTHER VEH. SLOW OR STOP	13	1.8	3	4.8
SLOW OR STOP - OTHER VEH. ENTERED ROAD	1	.1	0	0.0
SLOW OR STOP - TO MAKE RIGHT TURN	3	.4	0	0.0
SLOW OR STOP - TO MAKE LEFT TURN	10	1.4	0	0.0
NO CODE GIVEN WAS APPLICABLE	540	75.0	57	90.5
OTHER CODE GIVEN	14	1.9	0	0.0
TOTAL	720	100.0	63	100.0

*CTW - CONTINUOUS TWO-WAY LEFT-TURN MEDIAN LANE
**COW - CHANNELIZED ONE-WAY LEFT-TURN MEDIAN LANE
***HAS PRIORITY OVER OTHER CODES

TABLE 5.7. FACTORS RELATED TO ACCIDENTS AT UNSIGNALIZED INTERSECTION LOCATIONS

FACTOR DESCRIPTION	CTW*		COW** WITH CURB	
	NO. CASES	PERCENT OF COLUMN	NO. CASES	PERCENT OF COLUMN
VEH. PASSING ON LEFT	2	.6	0	0.0
VEH. CHANGING LANES	5	1.6	0	0.0
ONE VEH. ENTERING DRIVEWAY***	6	1.9	0	0.0
ONE VEH. LEAVING DRIVEWAY***	6	1.9	0	0.0
SWERVE - REASON NOT SPECIFIED	0	0.0	0	0.0
SWERVE - PEDESTRIAN, CYCLE, ETC.	0	0.0	0	0.0
SWERVE - OTHER VEH. STOPPED OR SLOWING	0	0.0	0	0.0
SWERVE - OTHER VEH. ENTERED ROAD	4	1.3	0	0.0
SLOW OR STOP - REASON NOT SPECIFIED	2	.6	2	3.3
SLOW OR STOP - TRAFFIC CONTROL - OFFICER	8	2.6	0	0.0
SLOW OR STOP - PEDESTRIAN, CYCLE, ETC.	1	.3	0	0.0
SLOW OR STOP - OTHER VEH. SLOW OR STOP	11	3.5	0	0.0
SLOW OR STOP - OTHER VEH. ENTERED ROAD	1	.3	0	0.0
SLOW OR STOP - TO MAKE RIGHT TURN	3	1.0	0	0.0
SLOW OR STOP - TO MAKE LEFT TURN	9	2.9	2	3.3
NO CODE GIVEN WAS APPLICABLE	231	74.5	55	90.2
OTHER CODE GIVEN	21	6.8	2	3.3
TOTAL	310	100.0	61	100.0

*CTW - CONTINUOUS TWO-WAY LEFT-TURN MEDIAN LANE
**COW - CHANNELIZED ONE-WAY LEFT-TURN MEDIAN LANE
***HAS PRIORITY OVER OTHER CODES

Tables 5.6 and 5.7 compare factors at signalized and unsignalized intersections. A large number of cases in both of these tabulations are in the category of "no code given was applicable." For the signalized intersections it is interesting to note that the category of "slow or stop for a traffic control" is of much more importance on CTWLTML sites than on raised COWLTML sites. Table 5.5 shows an opposite trend. However, comparisons of that table's totals with values plotted on Fig 5.6 reveal that, on a realtive basis, Table 5.5 contains a higher percentage of intersection-related accidents for the raised COWLTML cases than for the CTWLTML. Therefore, the trends in relation to vehicles slowing or stopping for a traffic control device must be made on a comparison of the totals, which reveals that 15 percent of the total cases for CTWLTML sites and 17 percent of the cases for raised COWLTML sites are in this category - an inconclusive difference.

REGRESSION ANALYSIS

As discussed in previous chapters, a multiple regression analysis was chosen to aid in identifying relationships between accident and site characteristics. Through this analysis, the predictabilities of the number of accidents and accident rates are examined and characteristics of accident sites which do not follow usual patterns are identified. Appendix A lists the mean and standard deviations for all variables used in the regression analysis.

Equations Developed

Table 5.8 presents a summary of the equations developed in the regression analysis. The partial F values for inclusion or deletion of variables in the equations were set at levels corresponding approximately to 10 and 20 per cent significance levels, respectively.

Equations 1 through 10 were developed using individual midblock sites (short sections between two adjacent intersections) with exclusion of all intersection accidents. Due to the poor predictability of accidents on midblock sites and the large numbers of variables entering the equations, individual midblock sites were quickly dropped from the analysis. Separation of the midblock sites by lane type did little to improve the equations.

TABLE 5.8. SUMMARY OF REGRESSION ANALYSIS EQUATIONS

Eq No.	Description	Intersection Accidents Included	Dependent Variables Name	Mean	Standard Deviation	Sample Size	Number of Variables	R^2	Standard Error of Residuals	F_{reg}
1	All Midblocks	No	XNTAM	4.500	4.767	212	9	.55	3.273	27.3
2	"	"	XNLTAM	.6179	1.026	"	5	.29	.8761	16.7
3	"	"	XTAMMM	691.4	631.0	"	7	.34	521.1	15.1
4	"	"	XLTMMM	93.92	159.0	"	2	.05	155.9	5.2
5	"	"	XAMM	50.08	51.45	"	11	.53	36.27	20.4
6	"	"	XLTMM	6.254	9.661	"	4	.15	8.994	9.1
7	"	"	SIM	.1660	.2618	"	6	.15	.2456	5.8
8	"	"	CRM	5559	3406	"	7	.39	2709	18.5
9	"	"	ADSM	1.397	.9220	"	7	.24	.8196	9.0
10	"	"	A-IR	2.981	3.191	"	10	.51	2.280	21.2
11	All Sections	No	XNTA	17.22	14.32	76	3	.68	8.292	50.6
12	"	"	XNLTA	2.410	2.560	"	2	.45	1.924	29.7
13	"	"	XTAMM	641.2	401.6	"	7	.69	234.0	21.9
14	"	"	XLTMM	95.98	100.2	"	3	.40	79.17	16.1
15	"	"	XAM	45.66	40.47	"	9	.81	18.62	32.1
16	"	"	XLTM	6.431	7.203	"	3	.62	4.535	39.1
17	"	"	SI	.1861	.1676	"	1	.11	.1595	8.8
18	"	"	CR	3101	1284	"	8	.71	735.2	20.2
19	All Sections	No	ADS	1.626	.5136	76	3	.31	.4360	10.7
20	All Sections	Yes	XNTA	28.80	20.15	76	6	.77	10.09	38.3
21	"	"	XNLTA	7.132	5.449	"	4	.60	3.561	26.1
22	"	"	XTAMM	1124	694.6	"	7	.67	420.2	19.6
23	"	"	XLTMM	287.2	231.1	"	5	.48	171.7	13.2
24	"	"	XAM	77.09	62.03	"	10	.83	27.13	32.7
25	"	"	XLTM	19.26	17.63	"	12	.77	9.161	17.9
26	"	"	SI	.2022	.1181	"	4	.19	.1094	4.1
27	"	"	CR	4430	1806	"	5	.63	1133	24.1
28	"	"	ADS	1.702	.3649	"	3	.27	.3185	8.8
29	CTW Sections	No	XNTA	16.90	13.04	62	3	.69	7.498	42.2
30	"	"	XNLTA	2.500	2.572	"	2	.43	1.968	22.6
31	"	"	XTAMM	656.3	394.7	"	6	.67	239.3	18.5
32	"	"	XLTMM	100.1	96.42	"	5	.44	75.40	8.8
33	"	"	XAM	46.04	38.41	"	7	.81	17.62	33.7
34	"	"	XLTM	6.784	7.319	"	4	.63	4.611	24.2
35	"	"	SI	.2053	.1746	"	2	.12	.1666	4.0
36	"	"	CR	3193	1365	"	7	.72	773.3	19.4
37	"	"	ADS	1.616	.5313	"	4	.37	.4374	8.2
38	CTW Sections	Yes	XNTA	28.27	19.22	62	5	.75	10.07	33.3
39	"	"	XNLTA	7.000	5.516	"	7	.69	3.259	17.3
40	"	"	XTAMM	1143	730.1	"	10	.81	343.5	22.5
41	"	"	XLTMM	286.9	237.8	"	10	.67	158.6	9.5
42	"	"	XAM	77.87	61.40	"	12	.88	23.27	31.3
43	"	"	XLTM	19.44	18.33	"	10	.76	9.795	16.3
44	"	"	SI	.2098	.1249	"	5	.29	.1099	4.5
45	"	"	CR	4514	1950	"	4	.67	1163	28.6
46	"	"	ADS	1.697	.3566	"	3	.31	.3034	8.8

Sections were formed by combining midblock and intersection data in a manner which provided as much homogeneity over the site as possible. This was done in terms of the level of development, number of accidents, volume, speed, lane type, markings, parking, lane widths, etc. In addition, features such as railroad tracks, highly skewed intersections, etc. were avoided. The sections averaged approximately .45 mile in length; extremely long sections which remained homogenous rarely occurred, and extremely short sections were avoided.

The sections were analyzed with and without the inclusion of intersection accidents. This enabled an examination of the effects of intersection accidents on the total number of accidents, thereby providing another means of comparing lane types with the evaluation of the variability of other factors with and without intersection accidents included. As shown in Table 5.8, inclusion of intersection accidents generally improved predictability of equations concerning accidents and accident severity and lessened the predictive ability of the equations related to the critical accident rate and the average damage scale.

The sites were examined with combinations of lane types and with separation of the CTWLTML sections. COWLTML sections were too few in number for an adequate regression analysis. The predictive abilities of the equations generally improved slightly when the CTWLTML sections were considered by themselves, indicating that some differences probably exist between characteristics of the CTWLTML and COWLTML sites.

Checks of Regression Assumptions

Plots of residuals versus dependent and independent variables were examined to identify inadequacies of the models and to provide clues for possible variable transformations which might improve the equations. The plots of residuals versus dependent variables for the single midblock sites exhibited linear residual patterns with positive residuals on one end of the dependent variable range and negative residuals on the other. These patterns, which resulted from the large number of site variables which had zero values on the short sections and from a mixture of lane types, rendered the midblock site equations inadequate for predictive purposes. Similar patterns were observed for the equations developed using mixed lane types. Although the patterns were not as strong as in the case of the midblock sites, the equations would still be judged as inadequate. These patterns illustrate further that there are differences between the CTWLTML sites and the COWLTML sites.

Residual patterns similiar to those related to the midblock site equations were also observed for equations predicting the severity index, critical rate, and average damage scale, for reasons similar to those previously discussed. For the section equations developed from the CTWLTML sites, the residual patterns were extremely slight or exhibited the normal absence of pattern. The equation which was chosen for predictive purposes on CTWLTML sections presented no residual problems.

Improving the Equations

Little effort was expended to improve statistics on the equations which were shown to be inadequate. The primary concentration was on improving the prediction equations for the CTWLTML sections with intersection accidents included, since these equations provide the information most needed by traffic engineers. Variable transformations were based primarily on findings of previous studies using multiple regression and on patterns of residuals versus independent variables. Complex transformations were avoided in the analysis to maintain an intuitive feel for the variable relationships. Based on the statistics presented in Table 5.8 and on comparisons with related studies, equations 38 through 43 appear to have very satisfactory predictive ability.

REGRESSION ANALYSIS RESULTS

Examination of the regression equations, residual plots, extreme cases, etc. revealed many important relationships between accident and site characteristics. The following is a summary of the most important findings of the regression analysis, with a concentration on CTWLTML equations.

Important Variables

In order to identify variables which are of greatest importance in relation to accidents at the study sites, Table 5.9 was prepared to show the most important variables which entered the developed equations. A maximum level of five independent variables was set to reduce the number of variables to a

TABLE 5.9. PRIMARY INDEPENDENT VARIABLES IN EQUATIONS

Eq. No.	Description	Intersection Accidents Included	Dependent Variable	Primary Independent Variables	R^2
1	All Midblocks	No	XNTAM	VEHMI, AS1, TWADT, TNDR, AS2	.49
2	"	"	XNLTAM	XNAC, XNACM, XCTWT, TWADT, TNDR	.29
3	"	"	XTAMMM	AS1, AS2 LGSECL, CISZ, XLTWI	.30
4	"	"	XLTMMM	TNDR, XCTWT	.05
5	"	"	XAMM	TWADT, AS1, AS2, LGVEHM, CISZ	.45
6	"	"	XLTMM	TNDRM, CISZ, XCTWT, XLTYP1	.15
7	"	"	SIM	DIOSZ, XLTWI, LGADT, AS1, XLEG2	.13
8	"	"	CRM	LGSECL, XLTWI, AS2, AS1, SECLEN	.37
9	"	"	ADSM	DCBD, XLTWI, LGVEHM, ATHWI, VEHMI	.21
10	"	"	A-IR	VEHMI, PVAC, SECLEN, TNDR, LGADT	.45
11	All Sections	No	XNTA	TWADT, TNDR, XNAS1	.68
12	"	"	XNLTA	XNACM, VEHMI	.45
13	"	"	XTAMM	PAC, XNSPM, TNDRM, XNAC, CISZ	.64
14	"	"	XLTMM	XNACM, VEHMI, XCTWT	.40
15	"	"	XAM	TWADT, TNDRM, TNDR, XNSPM, PPLT	.77
16	"	"	XLTM	XNACM, XNAC, XCTWT	.62
17	"	"	SI	CISZ	.11
18	"	"	CR	SECLEN, XNSPM, VEHMI, XLTWI, PAC	.62
19	"	"	ADS	DIOSZ, CISZ, XLTWI	.31
20	All Sections	Yes	XNTA	TWADT, XNSIG, TNDR, CISZ, PKG1	.76
21	"	"	XNLTA	XNACM, XNSIG, CISZ, VEHMI	.60
22	"	"	XTAMM	XNSPM, SECLEN, PAC, XLTWI, CISZ	.61
23	"	"	XLTAMM	PAC, VEHMI, CISZ, XNSPM, PKG2	.48
24	"	"	XAM	TWADT, XNSPM, VEHMI, XNACM, CISZ	.75
25	"	"	XLTM	PAC, TWADT, VEHMI, XNSPM, CISZ	.59
26	"	"	SI	CISZ, PKG2, TWADT, XNSPM	.19
27	"	"	CR	VEHMI, XNSPM, PAC, XNAC, XLTWI	.63
28	"	"	ADS	DIOSZ, XLTWI, XCHLT	.27
29	CTW Sections	No	XNTA	TWADT, TNDR, XNSIG	.69
30	"	"	XNLTA	XNACM, VEHMI	.43
31	"	"	XTAMM	XNSPM, TNDRM, TNDR, PPLT, XLTWI	.65
32	"	"	XLTMM	PAC, DIOSZ, CISZ, DCBD, PKG2	.44
33	"	"	XAM	TWADT, VEHMI, TNDRM, XNSPM, SECLEN	.79
34	"	"	XLTM	XNACM, XNAC, VEHMI, XCTWT	.63
35	"	"	SI	PVAC, XN3L	.12
36	"	"	CR	VEHMI, XNSPM, XNTHL, PAC, XNRESM	.67
37	"	"	ADS	DIOSZ, XLTWI, PVAC, CISZ	.37
38	CTW Sections	Yes	XNTA	TWADT, XNSIG, TNDR, CISZ, PKG1	.75
39	"	"	XNLTA	XNSIG, TWADT, CISZ, PKG1, DIOSZ	.65
40	"	"	XTAMM	XNSPM, CISZ, XNRESM, PAC, LGTNDR	.68
41	"	"	XLTMM	XNSPM, CISZ, VEHMI, PAC, PKG2	.51
42	"	"	XAM	TWADT, XNSPM, VEHMI, CISZ, TNDRM	.75
43	"	"	XLTM	CISZ, XNSPM, TNDRM, TNDR, XN4L	.66
44	"	"	SI	CISZ, THRUSL, XN4L, XNSIG, XLTSL	.29
45	"	"	CR	VEHMI, XNSPM, XNTHL, XNPUBM	.67
46	"	"	ADS	DIDSZ, XLTWI, PKG2	.31

manageable set. Values of R^2 for the reduced equations are given for comparison to Table 5.8 and to illustrate the importance of the independent variable sets.

Dependent Variables. The best dependent variables for prediction of all types of accidents on CTWLTML sections appear to be (in order of value) the number of accidents per vehicle mile, the total number of accidents, and the number of accidents per million vehicle miles. The left-turn accident variables follow the same pattern. The amounts of variability explained by the equations are generally higher for the CTWLTML sections with the intersection accidents are included.

The severity index and average damage scale were very unpredictable, as was expected. The equations for prediction of the severity index and average damage scale also were found to be inadequate due to previously mentioned residual plot patterns. The critical accident rate was used as a dependent variable to aid in spotting unusual conditions. Then R^2 values are somewhat misleading since the critical rate was developed using vehicle-miles, the primary independent variable for predicting the critical rate.

Independent Variables. The independent variables given in Table 5.9 show that independent variables expressed as rates are associated with dependent variables as rates, and independent variables not expressed as rates are associated with dependent variables which are not expressed as rates. For example, equations for predicting the number of accidents have the number of signals as an independent variable; accidents which are expressed as rates have the number of signals per mile as an independent variable.

The most consistently important independent variables are weekday ADT, number of signals (or number of signals per mile), number of driveways (or number of driveways per mile), and the city size. Other important variables are vehicle-miles of travel (per weekday), percent commercial land use, and the existence of curbside parking.

ADT has been frequently related to accident rates and was expected to be an important variable. ADT is a measure of both exposure and congestion on the sections. "Vehicle-miles of travel" is a measure of interaction between the ADT and the section length. By using an average section length, the vehicle-miles of travel measure can be eliminated from the equations, which is desirable when ADT has already been entered into the equation.

The number of signal and number of driveway measures are logical entries since both are indirect measures of level of development and conflicting movements. It is also important to note that the number of signals on the site is important even when intersection accidents are not included. The inclusion of a signal variable illustrates the importance of signal effects on accidents not actually occuring at intersections.

The inclusion of the city size variable may be partially a measure of the differences in character of the cities in which the sections are located; however, the variable may also be a good measure of the frequency of major cross streets and of other factors such as peaking effects and congestion. This is illustrated by the fact that city size is of much more importance in prediction of CTWLTML accidents when intersection accidents are included in the number of accidents and calculation of accident rates, both left-turn and total.

As might be expected, percentage of land use classified as commercial appears to influence accident numbers and rates. Commercial land use influences appear to be more prevalent on the CTWLTML sections when intersection accidents are not included and in the prediction of left-turn accidents and rates, illustrating the importance of commercial land use in generating mid-block left turns and the greater need for left-turn provisions in commercial areas. The high colinearity between percent commercial land use and number of driveways per mile (.671) generally deterred both variables from entering the same equation since partial F's are calculated in each step of a stepwise regression and one variable would not add significantly to the equation in the presence of the other.

The dummy variables for parking conditions entered several of the equations and illustrate that slight increases in accident numbers and rates may occur where curbside parking is permitted.

It is also important to note the absence of other variables which were considered to be important as identified from the literature. Lane widths were not shown to be of major importance in the analysis, which may be primarily due to the provision of adequate lane widths. Lane width may be an important factor when it is excessively large or small. This would indicate that presently used lane widths are adequate. The average left-turn lane width for the CTWLTML sections is 11.7 feet; therefore a 12-foot lane could be considered desirable in terms of effects on accidents. Similarly, there is no evidence from the analysis that present speed limits are unsafe or that posted speed limits for CTWLTML's significantly reduce accident numbers or rates.

Prediction of Accident Rates

CTWLTML's. Application of the regression analysis to prediction of accident rates requires selection of an equation which provides the "best" estimates of rates. As discussed, the best dependent variable for predicting accident rates on CTWLTML sections is the number of accidents per mile. The accidents per mile equation also provides logical independent variables which consistently demonstrate relationships to accidents. These independent variables are weekday ADT, number of signals per mile, number of driveways per mile, and city size. Although "vehicle-miles of travel" also entered the equation, it was eliminated several steps later. The vehicle-miles variable was eliminated by using the average section length as previously described. The equation developed is

$$\begin{aligned}\text{Accidents/mile} \;=\; & -43.5 + 0.00203(\text{ADT}) + 0.000175(\text{City Population}) \\ & + 0.491(\text{Number of Driveways/mile}) \\ & + 9.20(\text{Number of Signals/mile})\end{aligned}$$

The standard error for the residuals is approximately 33 accidents/mile, the F_{reg} is approximately 34, and the value of R^2 is approximately 0.75.

Although the equation shows that the number of accidents per mile increases with each of the independent variables, Table 5.10 better illustrates the magnitude of the expected accident rates. The variable ranges and averages used for development of Table 5.10 were derived from the data for the study sites used in the analysis. Numbers of observations in the cells and other checks were made to assure that the values in the table were not out of range

TABLE 5.10. ESTIMATED ACCIDENTS PER MILE ON CTWLTML SECTIONS

Four-Lane Urban Streets Average Section Length = 0.44 miles		Under 15,000 ADT (10,540)			15,000 - 20,000 ADT (17,500)			Over 20,000 ADT (24,500)		
		50,000 pop.	250,000 pop.	400,000 pop.	50,000 pop.	250,000 pop.	400,000 pop.	50,000 pop.	250,000 pop.	400,000 pop.
Over 3 spm (4.63)	Over 60 dpm (87.7)	72.3	107.3	133.5	86.4	121.4	147.6	100.6	135.6	161.8
	40-60 dpm (50)	53.9	88.9	115.1	68.0	103.0	129.2	82.2	117.2	143.4
	Under 40 dpm (22.7)	40.4	75.4	101.6	54.5	89.5	115.7	68.7	103.7	129.9
1 - 3 spm (2.0)	Over 60 dpm	48.1	83.1	109.3	62.2	97.2	123.4	76.4	111.4	137.6
	40-60 dpm	29.7	64.7	90.9	43.8	78.8	105.0	58.0	93.0	119.2
	Under 40 dpm	16.2	51.2	77.4	30.8	65.3	91.5	44.5	79.5	105.7
0 spm	Over 60 dpm	29.7	64.7	90.9	43.8	78.8	105.0	58.0	93.0	119.2
	40-60 dpm	11.3	46.3	72.5	25.4	60.4	86.6	39.6	74.6	100.8
	Under 40 dpm	0.0	32.8	59.0	11.9	46.9	73.1	26.1	61.1	87.3

ADT = Weekday Average Daily Traffic

spm = signals/mile

dpm = driveways/mile

( ) = Average values used for table development of the predictive capabilities of the regression model. The average accident per mile rate for the CTWLTML sites with intersection accidents included is 77.9 accidents per mile. The average rate for the values in Table 5.10 is 79.5 accidents per mile.

Non-CTWLTML's. Although there were too few non-CTWLTML sites for a regression analysis, comparison of these sites to the CTWLTML sites can provide some insight into differences in the lane types. Table 5.11 illustrates why this model cannot be used for COWLTML sites through a tabulation of COWLTML and reversible lane site accident rates in comparison with estimated accident rates for CTWLTML sites with the same characteristics. This expedient comparison shows a consistent overestimation of accident rates on raised COWLTML sites by the accident rate equation developed for CTWLTML sites. The comparison illustrates why the equations developed for all lane types in combination were not satisfactory; therefore, the model should not be used to estimate accidents per mile on COWLTML. The results are meaningless and erroneous conclusions could result.

Other Observations

In order to identify conditions which might make a particular site have an unusually low or high accident rate, sites were identified which seemed to be "set apart" from the others.

The critical rate value for each of the CTWLTML sites was compared with the accident rate for the site. If a site accident rate is larger than the critical rate for that site, the deviation of the rates is probably not due to chance alone and the site should be examined further. However, none of the CTWLTML sites had an accident rate greater than its critical rate and no particular sites were identified for further examination by this method.

A second means of identifying sites for study was to examine all sites whose observed rates were over two standard deviations from the predicted rate and to examine rates of unusual sites. Although these examinations offer no real statistical basis for conclusions, they can provide more insight into the variabilities and relationships of accidents. Lower than usual accident rates are believed to be related to low volume turn sites, such as where there is vacant land or the land is not accessed from the site directly (e.g., railroad track parallel to site, sides of houses facing the site, commercial access

TABLE 5.11. COMPARISON OF ACCIDENT RATES BY LANE TYPE

Lane Type	Number of Through Lanes	ADT	Population	Signals Per Mile	Driveways Per Mile	Actual Accidents Per Mile	Estimated CTWLTML Accidents Per Mile	Error (Actual-CTWLTML)
Raised COWLTML	6	29562	407,000	4.17	39.6	166.7	145.5	21.2
" "	6	31134	"	4.65	39.5	127.9	153.2	-25.3
" "	6	32706	"	3.13	84.4	253.1	164.3	-88.7
" "	4	15483	"	0.0	16.1	41.9	67.1	-25.2
" "	4	13921	"	0.0	31.3	12.5	71.4	-58.9
" "	4	13591	"	0.0	0.0	9.4	55.4	-46.0
" "	4	14477	"	0.0	81.8	65.9	97.3	-31.4
" "	4	14477	"	0.0	100.0	76.3	106.3	-30.0
" "	4	14477	"	2.1	62.5	64.9	107.0	-42.4
" "	4	8323	283,700	0.0	17.0	36.2	31.4	4.8
" "	6	13660	"	3.2	35.5	29.0	81.0	-52.0
Flush COWLTML	4	17197	407,000	0.0	23.3	46.4	74.1	-27.6
Reversible	2	13223	283,700	2.0	56.0	66.0	78.9	-12.9
"	2	11367	"	2.9	5.9	35.3	59.2	-23.9

Avg. Error = -18.6

Avg. Error (Raised) = -31.8

Avg. Error (4 lane, Raised) = -33.4

from a side street). Higher accident rates are believed to be related to sites where the commercial land use is either a single large generator (e.g., a large shopping center) or a series of businesses with many drives (e.g., a high density strip commercial); higher rates may also be associated with sites where persons are entering the section from a low density rural area at higher speeds and entering a more highly developed area. Higher rates were also verified where the ADT is very high, the number of signals or drives is high, or parking is permitted.

SUMMARY

The data analysis segment of the accident study shows that left-turn lanes are applied over a wide range of conditions. Differences between CTWLTML and raised COWLTML sites are shown in terms of where accidents occur on the sites, the factors which contribute or are related to accidents, the accident rates that occur, and the site variables that influence accident rates on CTWLTML sections. Figure 5.10 provides guidance in the evaluation of CTWLTML. Similar predictive equations for COWLTML were not possible; therefore, CTWLTML predictions may be used to "test" against. In addition, the appearance of the "city population" parameter in the predictive equation and the absence of study locations in cities larger than one million suggests caution in the use of the comparison of accident rates in very large cities (greater than one million in population).

CHAPTER 6. OPERATIONAL STUDY DATA COLLECTION

The comparison of individual sites where median left-turn lanes have been implemented can aid in evaluating the operational characteristics of left-turn lanes. This evaluation can lead to a better understanding of traffic flow through median left-turn facilities, optimum design characteristics, and possible traffic hazard characteristics. This chapter discusses the data collection process and presents a description of the data itself.

SITE AND DATA SELECTION

Five situations which included most of the typical situations for the left-turn facilities were identified. These situations were (1) short block, (2) offset intersections, (3) offset driveways, (4) one-side left-turns only, (5) other commonly used situations.

The selection process involved reviewing locations in several cities and inventorying those sites that fitted the selection criteria. These criteria were based on land use, left-turn facility, average daily traffic volume, posted speed limit, and the type of delineation. A total of 20 sites were selected in Austin and in Fort Worth, Texas. Nine of the sites in Austin are continuous two-way left-turn median lanes (CTWLTML), four of these being CTWLTML's with transitions from CTWLTML's to either raised or flush COWLTML's at the intersection. The five other Austin sites are either raised or flush channelized one-way left-turn median lanes (COWLTML). The remaining six sites in Fort Worth have either an extreme width or a different delineation. A brief summary of the sites is shown in Table 6.1.

Various operational characteristics mentioned in the literature were considered in the data selection process. The data requirements adopted for this study were entrance distance, maneuvering distance, lateral placement, traffic volume, and conflicts.

TABLE 6.1. SUMMARY OF SELECTED SITES

Location	Type of left turn lane	ADT **	Speed Limit	Delineation
Austin:				
1. 5th & Lamar	CTWLTML	31,110	35	Single line white buttons; yellow square buttons at the intersection approach.
2. 6th & Lamar	CTWLTML	31,110	35	Single line white buttons; yellow square buttons at the intersection approach.
3. 45th & Lamar	CTWLTML/RAISED COWLTML	25,780	40	Standard CTWLTML marking* at midblock; opening; raised island at approach.
4. 45th & Guadalupe	CTWLTL/FLUSH COWLTML	23,210	35	Standard CTWLTML with buttons; opening; yellow square buttons at approach.
5. Anderson & Burnet	CTWLTML	22,570	40	Standard CTWLTML with buttons; large round buttons at approach.
6. Denson & Airport	CTWLTML	19,060	45	Standard CTWLTML with buttons.
7. Barton Spring & Lamar	CTWLTML/RAISED COWLTML	29,940	40	Single line white buttons; raised island at approach.
8. Riverside & Congress	CTWLTML/FLUSH COWLTML	21,340	35	Standard CTWLTML at midblock; opening; yellow square buttons at approach; 6 lanes with parking on one side.
9. 32rd & Red River	CTWLTML	12,240	30	Standard reversible lane* marking; 2 lanes; reversible lane during peak period.
10. 45th & Lamar	RAISED COWLTML	21,680	40	Standard COWLTML with raised island.
11. 19th & Lamar	RAISED COWLTML	25,790	35	Standard COWLTML with raised island on the right side.
12. 45th & Guadalupe	FLUSH COWLTML	20,730	35	Standard COWLTML with buttons.
13. Congress & 19th St.	FLUSH COWLTML	25,040	30	Standard COWLTML.
14. 26th & Guadalupe	COWLTML	26,980	35	Continuous one-way with buttons.
Fort Worth:				
15. Cockell & Berry	CTWLTML	19,500	35	Single line with buttons; double line with buttons at intersection; 6 lanes.
16. Wichita & Mansfield	RAISED	14,500	40	Raised island; 12" dia. metallic buttons on the other side.
17 Bigham & Camp Bowie	RAISED	28,700	35	Raised island; 8" dia. ceramic buttons on the other side.
18. Guliford & Camp Bowie	RAISED	32,200	35	Raised island; 8" dia. ceramic buttons on the other side.
19. University & W. Settlement	FLUSH	16,700	30	8" dia. ceramic buttons on both sides.
20. E. Vickery & S. Main	FLUSH	8,000	30	12" dia. metallic buttons on both sides.

* Refer to MUTCD

** ADT obtained from 1975 Volume Count furnished by the Texas Department of Highway and Public Transportation.

DATA COLLECTION PROCEDURE

These five operational characteristics were collected through several different methods. Each of these methods is briefly presented here. Appendix B gives a more detailed description of each method.

Entrance distance is the distance from an intersection to where a vehicle enters the turn lane before making a left-turn maneuver. These data apply to CTWLTML facilities since the COWLTML has specific openings provided for left-turn entry. The entrance distance for each car which entered each CTWLTML facility was recorded by two observers who recorded the distance from the stopping line of the intersection that the left front wheel touched the CTWLTML line. Maneuvering distance is the distance requried for the left-turn vehicle to fully enter the left-turn lane. The spot where the left front wheel touched the CTWLTML and the spot where the right rear wheel touched the CTWLTML was estimated by the same two observers. The distance between these spots is the maneuvering distance.

Lateral placement is the lateral position of the vehicle within the lane. It was collected through the use of a movie camera set on the roadside as far as possible from the roadway in order to minimize influence on the driver. One photograph, also, was taken whenever a vehicle entered the median left-turn facility. Three reference markers were used with two outside markers locating the outer edges and a third marker locating the center of the left-turn lane. Lateral deviation of the vehicle is the distance between the center line of the left-turn lane and the center line of the vehicle. This deviation was adjusted to the same scale as the actual roadway and was used later in the statistical analysis.

A clipboard counter was used to record the combined total for the through-lane volume, left-turn volume, and opposite volume. These volume counts were made simultaneously with the distance data collection and used as a relative descriptor of the site.

Conflict data include any frictions caused by vehicles turning left over the study section. They can also be misuses or erratic movements at the site. Only the peak period was observed since the higher volume would normally generate more conflicts.

Theoretically, five types of conflicts were identified as pertinent to the operation of CTWLTML. They are shown in Fig 6.1 and listed below:

(1) head-on conflict,

(2) conflict between vehicle in the CTWLTML and a left-turn vehicle from a minor street as it enters the CTWLTML,

(3) conflict between a vehicle in the CTWLTML and a vehicle that starts to enter the CTWLTML,

(4) conflict between a left-turn vehicle from the through lane (not using the CTWLTML) and a straight-through vehicle, and

(5) conflict between a vehicle in the CTWLTML and a left-turn vehicle from the through lane.

In a flush COWLTML, fewer types of conflicts are possible since fewer choices are available to the drivers. Possible types of conflicts for COWLTML are shown in Fig 6.2 and listed below:

(1) conflict between a left-turn vehicle and a straight-through vehicle in the through lane,

(2) conflict between a left-turn vehicle in the left-turn lane and a left-turn vehicle from the opposite direction, and

(3) conflict between a left-turn vehicle and a straight-through vehicle in the opposite direction.

On a raised COWLTML, even fewer conflict types are possible since conflicts with the opposite stream of traffic are eliminated. The only possible type of conflict, shown in Fig 6.3, is one between a left-turn vehicle and a through vehicle in the through lane.

The data collected for each site are presented in Appendix C. The volume data indicate the relative congestion at the site. The site diagram shows the land uses, location of driveways, and lane widths at each location. Personal observations relate traffic conflicts and erratic movements. The lateral placement is presented in two diagrams illustrating the location of the vehicle within the left-turn lane. One shows the average displacement of the vehicle from the center line of the left-turn lane and the other diagram shows the frequency of observation in 10-inch increments. Entrance and maneuvering distances illustrate the operational characteristics on CTWLTML. Frequency diagrams illustrate the frequency in 50-foot and 20-foot increments for entrance and maneuvering distances, respectively.

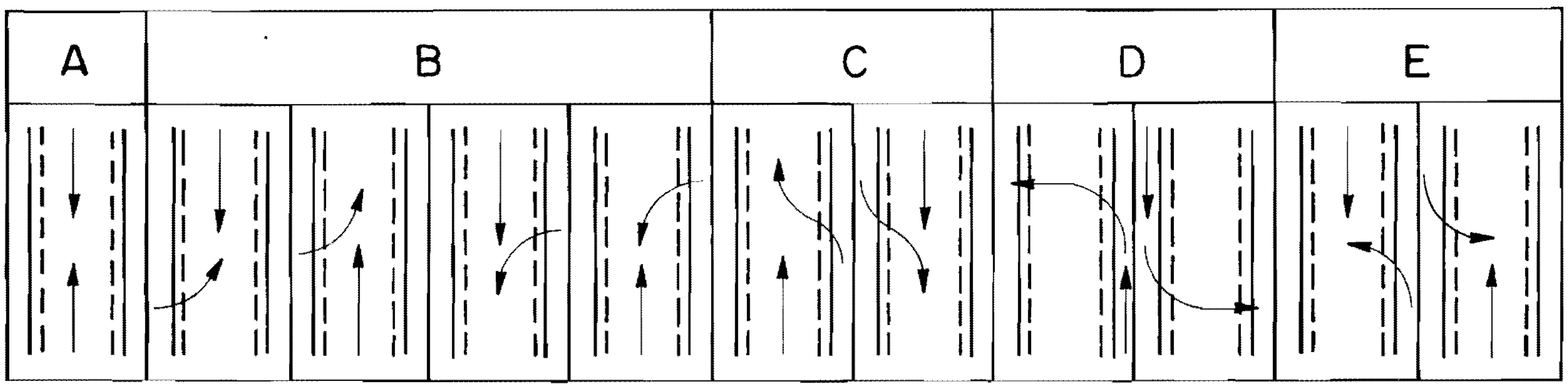


Fig 6.1. Possible left-turn related conflicts on CTWLTML.

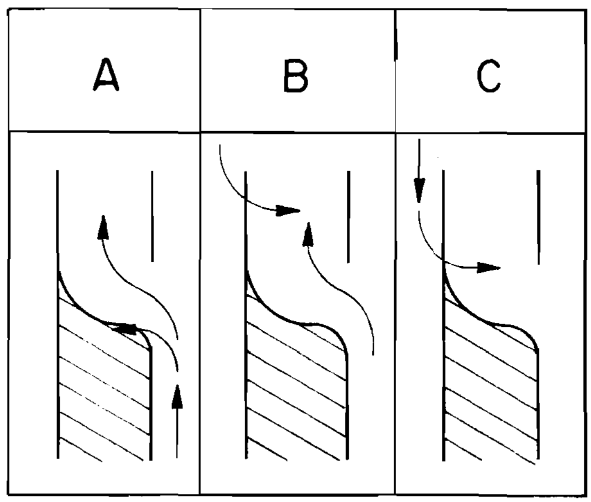


Fig 6.2. Possible left-turn related conflicts on flush COWLTML.

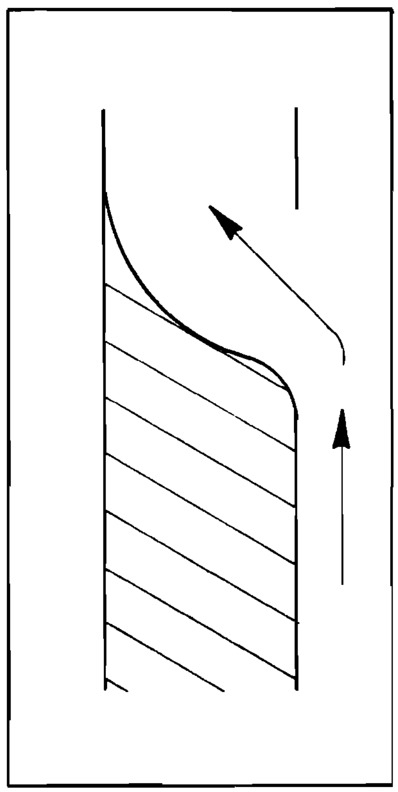


Fig 6.3. Possible left-turn related conflicts on raised COWLTML.

CHAPTER 7. OPERATIONAL STUDY DATA ANALYSIS

Statistical methods were used to analyze three types of data collected: vehicle lateral placement, entrance distance, and maneuvering distance. The data were further analyzed to ascertain the effect of different lane widths, different delineation systems, and different types of left-turn facilities. The results of the analyses provided some basic information on the proper width of the left-turn lane, the proper delineation system, and other related operational characteristics that can be used to develop the criteria for the left-turn lanes.

STATISTICAL METHOD

The method adopted for this analysis was the one-way analysis of variance method. It is a method which provides a basis for determining whether there is a significant difference between various sample means. The null hypothesis is that there is no significant difference between sample means. The "F" test is performed by finding the ratio between the mean squares "between" samples and "within" samples; this ratio is then compared with the standard "F" value found in the statistical tables. The tests were carried out on a 95 percent confidence level and were based on the following assumptions.

(1) Each sample is drawn randomly and independently from the population.

(2) The variances of the populations for all sets of data are equal.

(3) The populations for all sets of data are normally distributed.

If the calculated "F" value is larger than the table value, the hypothesis that there is no significant difference between various sample means will be rejected. This means that there are some differences between the tested samples.

LATERAL PLACEMENT

Four analyses were performed on the lateral placement data: (1) analysis with different lane widths, (2) analysis with different pavement markings,

(3) analysis with different types of left-turn lanes, and (4) analysis of the location of the raised island. A summary of the analyses is shown in Table 7.1.

Since each site has its particular characteristics and homogeneity between sites rarely occurs in a real world situation, sites selected for the analyses were based on five variables: lane width, type of marking, type of left-turn lane, lane use, and posted speed limit. One variable was normally tested at a time while the other four variables were held relatively similar between sites. In the lane width analysis, each type of left-turn facility was tested individually. On the CTWLTML, the results indicated a significant difference between an 11-ft. and a 15-ft. 3 in. lane, but almost no difference between an 11-ft. and an 11-ft., 10-in. lane. On the raised COWLTML, an 8-ft, 6-in. lane was found to be significantly different from a 10-ft, 6-in. lane. On the flush COWLTML, no difference was found between a 10-ft., 6-in. and a 12-ft., 4-in. lane.

In the pavement marking analysis, each type of left-turn lane was also tested individually. However, no two lanes with the same width were observed; therefore, a small variation in lane width was allowed for the analysis. On all the analyses, the results indicated significant differences between a standard CTWLTML marking with buttons and single line white button marking on a CTWLTML, and between paint and 8-in. diameter ceramic buttons on raised and flush COWLTML's.

In the left-turn facility analysis, a similar approach for the marking analysis was applied on the lane width problem. The results indicated a CTWLTML is significantly different from a CTWLTML/flush COWLTML, a raised COWLTML, and a flush COWLTML but that there is no difference between the latter three types of left-turn facilities.

In the location of raised island analysis, a similar approach for the marking analysis was applied on the lane width problem. From the result of the location of the raised island analysis it is obvious that drivers tend to lean farther away from the raised barrier, and the direction of leaning depends on the location of the raised barrier. This analysis clearly showed the effectiveness of the data collection technique because this result corresponds very well with an already known fact.

TABLE 7.1. SUMMARY ON LATERAL PLACEMENT ANALYSES

Type of Analysis	Location	Type of LT Lane	Calculated F Value	Table F Value	Significant Difference (*)
(1) Lane Widths					
11' vs 15'3"	Burnet & Anderson and Airport & Denson and Cockrell & Berry	CTWLTML	9.95	3.07	*
11' vs 11'10"	Burnet & Anderson and Airport & Denson	CTWLTML	.06	3.95	--
11' vs 15'3"	Burnet & Anderson and Cockrell & Berry	CTWLTML	10.91	3.95	*
11'10" vs 15'3"	Airport & Denson and Cockrell & Berry	CTWLTML	10.92	3.94	*
8'6" vs 10'6"	Bigham & Bowie and Guliford & Camp Bowie	Raised COWLTML	8.15	3.95	*
10'6" vs 12'4"	Guadalupe & 45th and Congress & MLK Blvd.†	Flush COWLTML	.88	3.99	--
(2) Pavement Markings	5th & Lamar and Burnet & Anderson	CTWLTML	171.25	3.95	*
	45th & Lamar (SB) and Guliford & Camp Bowie	Raised COWLTML	33.70	4.00	*

†Martin Luther King, Jr., Blvd.

(continued)

TABLE 7.1. (CONTINUED)

Type of Analysis	Location	Type of LT Lane	Calculated F Value	Table F Value	Significant Difference (*)
	Congress & MLK Blvd. and University & Wh. Sett.	Flush COWLTML	13.49	3.94	*
	45th & Lamar (NB) and Barton Sp. & Lamar	CTWLTML/ Raised COWLTML	23.08	4.00	*
(3) Left-Turn Lanes	Airport & Denson and Guadalupe & 45th (NB) and 45th & Lamar (SB) and Congress & MLK Blvd.	CTWLTML, CTWLTML/ Flush COWLTML, Raised COWLTML, Flush COWLTML	11.51	2.68	*
	Airport & Denson and 45th & Guad. (NB)	COWLTML, CTWLTML/ Flush COWLTML	25.09	3.96	*
	Airport & Denson and 45th & Lamar (SB)	CTWLTML, Raised COWLTML	25.71	3.98	*
	Airport & Denson and Congress & MLK Blvd.	CTWLTML, Flush COWLTML	10.33	3.96	*
	45th & Guad. (NB) and 45th & Lamar (SB)	CTWLTML/ Fl.COWLTL, Raised COWLTML	.75	4.03	--

(continued)

TABLE 7.1. (CONTINUED)

Type of Analysis	Location	Type of LT Lane	Calculated F Value	Table F Value	Reject H_o
	45th & Guad. (NB) and Congress & MLK Blvd.	CTWLTML/ Fl.COWLTL, Flush COWLTML	.96	3.99	--
	45th & Lamar (SB) and Congress & MLK Blvd.	Raised COWLTML, Flush COWLTML	2.19	4.03	--
	Burnet & Anderson and 45th & Lamar and Vickery & Main	CTWLTML, Raised COWLTML, Flush COWLTML	17.94	3.08	*
	Vickery & Main and Burnet & Anderson	Flush COWLTML, CTWLTML	21.90	3.94	*
	45th & Lamar (SB) and Burnet & Anderson	Raised COWLTML, CTWLTML	34.87	4.00	*
	Vickery & Main and 45th & Lamar (SB)	Flush COWLTML, Raised COWLTML	3.01	3.98	--
(4) Location of Raised Island	MLK & Lamar and 45th & Lamar (SB)	Raised COWLTML	20.32	4,06	*

ENTRANCE DISTANCE

Four analyses were performed on entrance distance: (1) entrance distance during peak and off-peak periods, (2) entrance distance at midblock and at intersections, (3) entrance distance on different types of pavement markings, and (4) entrance distance on different numbers of through lanes. A summary of the analyses is shown in Table 7.2.

The peak and off-peak period analyis is intended to be an indirect analysis of the effect of traffic volumes. The results indicated that the entrance distances were significantly different at various periods of the day or for different volumes. The only exception is at the intersection of Barton Springs and Lamar, which showed no significant difference. However, a closer look at the volumes indicated a relatively constant volume on the left-turn lane and the through lane next to the left-turn lane during peak and off-peak periods at this site. This result can be interpreted as an additional check to verify the effect of volume on entrance distance.

The site used for the midblock and intersection analysis is along Burnet Road. The turning roadways are about 500 feet apart and provide an ideal situation for the analysis. The results indicated the entrance distance at midblock is different from the entrance distance at the intersection. A closer examination of the data showed that drivers used shorter entrance distances at midblock than at the intersection. One of the reasons might be the signal installed at the intersection, which can be seen for a greater distance than the midblock driveway, which has no signal installation.

In the pavement marking analysis, the results at peak and off-peak periods showed significant differences between standard CTWLTML markings and single line white button markings. In the final analysis of the number of through lanes, the results also indicated a significant difference in entrance distances on five and seven-lane roadways.

MANEUVERING DISTANCE

Four analyses were performed on maneuvering distance: (1) maneuvering distance during peak and off-peak periods, (2) maneuvering distance at midblock and at the intersection, (3) maneuvering distance on different types

TABLE 7.2. SUMMARY ON ENTRANCE DISTANCE

Type of Analysis	Location	Calculated F Value	Table F Value	Significant Difference (*)
(1) Peak & Offpeak Periods	5th & Lamar	30.33	3.04	*
	6th & Lamar	131.26	3.03	*
	45th & Lamar	6.93	3.88	*
	Anderson & Burnet	5.68	3.88	*
	Barton Springs & Lamar	2.86	3.91	--
	Riverside & Congress	58.93	3.90	*
(2) Midblock & Intersect-ion	Anderson & Burnet	16.62	3.88	*
(3) Different Types of Markings	45th & Lamar and Barton Springs & Lamar (Offpeak)	32.68	3.89	*
	45th & Lamar and Barton Springs & Lamar (Peak)	6.58	3.88	*
(4) Total Number of Through Lanes	45th & Guadalupe and Riverside & Congress	68.54	3.86	*

of markings, and (4) maneuvering distance on different numbers of through lanes. A summary of the analyses is shown in Table 7.3.

In all the analyses with the exception of the type of pavement markings, the results corresponded very well with the results found in the entrance distance analyses. Maneuvering distance is found to be different at various periods of the day, at midblock, at intersections, and, finally, on five and seven-lane roadways. However, the analysis on markings showed no significant difference in terms of maneuvering distance.

SUMMARY

Lateral Placement

(1) The photographic technique adopted for the data collection proved to be effective and economical. However, the degree of accuracy depends on the quality standards imposed in data collection and reduction.

(2) On a CTWLTML there is almost no difference between lane widths of 11-ft. and 11-ft., 8-in., but there is some effect for a lane width of 15-ft., 3-in.

(3) On the 15-ft., 3-in. CTWLTML, the average displacement was found to be 21.6 inches left of the center line of the lane (Fig C49). The variance of the displacement is 929.83, an indication of inconsistency in using the lane.

(4) On a flush COWLTML, the results for 10-ft., 6-in. and 12-ft, 4-in. lanes showed no operational differences.

(5) On a raised COWLTML, there was a significant difference between lane widths of 8-ft, 6-in. and 10-ft., 6-in.

(6) Drivers tended to react more consistently on the 8-ft., 6-in. COWLTML lane. However, this consistency might result from the constrained roadway space which caused drivers to drive in the lane with greater caution and possibly reductions in operating speed.

(7) Standard CTWLTML markings and white single line button markings were interpreted differently by drivers.

(8) There were some operational differences between the use of paint and buttons for delineation.

(9) There was no significant difference between results for a raised COWLTML with paint markings and a flush COWLTML with 12-inch diameter metallic buttons on both sides of the lane.

TABLE 7.3. SUMMARY ON MANEUVERING DISTANCE

Type of Analysis	Location	Calculated F Value	Table F Value	Significant Difference (*)
(1) Peak & Offpeak Periods	5th & Lamar	11.77	3.04	*
	6th & Lamar	14.89	3.03	*
	45th & Lamar	4.02	3.88	*
	Barton Springs & Lamar	.65	3.92	--
	Riverside & Congress	14.65	3.90	*
(2) Midblock & Intersect-ion	Anderson & Burnet	6.56	3.89	*
(3) Different Types of Markings	45th & Lamar and Barton Springs & Lamar (Offpeak)	.08	3.91	--
	45th & Lamar and Barton Springs & Lamar (Peak)	.18	3.89	--
(4) Total Number of Through Lanes	45th & Guadalupe and Riverside & Congress	106.76	3.88	*

(10) There were significant differences between CTWLTMLs and flush COWLTMLs with 12-inch diameter metallic buttons on both sides of the lane.

(11) In a raised COWLTML, drivers tended to move farther away from the raised barrier.

Entrance Distance

(1) Volume has a significant effect on entrance distance, especially the left-turn volume and the volume for the through lane next to the left-turn lane on the same approach.

(2) Entrance distances at midblock and at intersection approaches are different.

(3) Shorter entrance distances were observed at midblock than at intersection approaches. The reason is probably the sight distance, i.e., a signal would indicate the location of the intersection far in advance of when the driver would be aware of the driveway with no signal installation.

(4) Delineations such as standard CTWLTMLs and white single line buttons have significant effects on entrance distance.

(5) Differing numbers of through lanes showed some significant effects on entrance distance.

(6) There is a wide range of entrance distances on CTWLTML's; the majority of drivers entered the CTWLTML 150 to 250 feet from the intersection, and very few drivers entered the lane less than 100 feet from the intersection.

(7) At the site with a frontage road, the entrance distance was observed to be farther from the intersection than at sites without frontage roads.

Maneuvering Distance

(1) There is a range of maneuvering distances; however, a large number of drivers completed the left-turn entry in 50 feet.

(2) Volume also showed a significant effect on maneuvering distance.

(3) Maneuvering distances at midblock and at intersection approaches are different; the distance tends to be shorter at midblock than at the intersection approach.

(4) On the reversible lane facility, maneuvering distances were observed to be longer than usual. A probable reason is that unfamiliarity with the lane caused drivers to be hesitant to use it.

(5) Standard CTWLTMLs with buttons and white single line buttons were interpreted in a similar manner by the drivers in terms of maneuvering distance.

(6) Differences in the number of through lanes showed some significant effects on the maneuvering distance used by drivers.

(7) In some cases, such as the short block situation, the maneuvering distance was dependent on the availability of maneuvering space in the left-turn lane. At the block of 5th and 6th Streets at Lamar, the high NB left-turn demand onto 6th Street during the evening peak period occupied the entire left-turn lane and left only a short spacing and sometimes no spacing at all for the SB left-turn traffic onto 5th Street (5th and 6th Streets are one-way).

Personal Observation

(1) A CTWLTML provides flexibility to help traffic engineers to utilize existing roadways to handle the increasing volume at a minimum cost.

(2) A CTWLTML can provide additional storage space for short block situations where the demand for left turns changes with time.

(3) Conflicts that were expected on a CTWLTML seldom occurred in typical situations except at offset driveways and short block situations.

(4) Conflicts that occurred on a CTWLTML were usually resolved by the involved motorists without difficulty.

(5) Uniformity and consistency of markings would probably provide a clear definition of the CTWLTML for local and out-of-town drivers.

(6) Overhead sign effectiveness is questionable in aiding use of CTWLTML's. They can be used to provide information on the proper entrance and exit points.

(7) A speed limit imposed on a CTWLTML serves very little purpose and is often ignored by the drivers.

(8) CTWLTML's were seldom used as an acceleration lane by the motorists entering the roadway from the driveway unless there were vehicles approaching on the through lane.

(9) In the situation where there is a high and concentrated left-turn demand, a proper barrier, such as a raised island or concrete bars, should be installed to separate the left-turn lane from the opposing through lane. This type of installation provides an exclusive shelter for left-turn motorists to finish their maneuvering in and also minimizes the conflicts with the opposing through traffic which tries to make left turns by crossing both the left-turn and the through lanes.

(10) Raised and flush COWLTML's gave no problems to the drivers in terms of conflicts except where inadequate storage space was provided to handle the left-turn queue.

(11) Half-inch-high square buttons and 3-inch-high, 8-inch-diameter buttons installed at the intersection approach to separate opposing traffic were not very effective in prohibiting left turns from the opposing traffic.

(12) Raised COWLTML's are effective in separating opposing traffic and provide exclusive lanes for left turns.

(13) Twelve-inch metallic buttons are effective in separating through-lane traffic and left-turn-lane traffic. However, several disadvantages are that (a) the buttons are difficult to maintain and clean, (b) they create hazards to motorcyclists, and (c) they force motorists who entered the left-turn lane by mistake to turn at the intersection. Few vehicles were observed returning to the through lane at the intersection and few vehicles entered the left-turn lane by crossing through the space between buttons.

CHAPTER 8. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

The objective of this study was to provide user information and decision making guidance on the accident and operational characteristics of left-turn facilities, especially CTWMLT lanes. This chapter provides a summary of the analysis of the data collected from the field studies. Recommendations are provided for use by practictioners in the evaluation of alternative left-turn lane options on urban arterial facilities.

To achieve the study objectives, several phases were developed and implemented over a two-year time frame.

Phase 1. Identification and Documentation of Current Design Practices.
Pertinent literature was reviewed and a survey of current design practices conducted throughout the cities and Texas State Department of Highways and Public Transportation personnel in Texas.

Phase 2. Evaluation of Median Design Options
The design and operational aspects of median design practices for urban arterials were examined. Special emphasis was on CTWLTML lanes and attention was given to raised and flush COWLTML lanes. This phase included field studies and data analysis.

Phase 3. Design and Operational Recommendation.
The analysis and evaluation conducted in development phases facilitated the recommendation of guidelines for use by highway designers and traffic engineers. Emphasis was placed on accident prediciton and traffic operational aspects.

Phase 4. Report Preparation
Information surveyed and recommended guidelines were reported through the preparation and transmittal of the final report.

SUMMARY

The summary presents the findings of the literature and survey results and the field studies and data analysis.

Literature and Survey Results

The following points surfaced during the investigation of the literature and survey evaluation (Ref 143).

(1) Although many factors are recognized as affecting accident rates and operational characteristics, two of the most important are:

* the site location (urban or rural)
* degree of access control

(2) Although a number of factors must be considered in determining left-turn lanes needs and design types, the most important are:

* existing site conditions
* degree of access control
* effects of left-turning vehicles on traffic flow and accident experience

(3) Typical observations for CTWLTML:

* ADT of 10-20,000 vpd
* 30-50 mph speed limit
* commercial land use adjacent to arterial

(4) Typical observations for COWLTML:

* ADT in excess of 10,000 vpd
* speed limits over 30 mph
* found in all forms of adjacent land use types

(5) Engineers surveyed in Texas suggested a hierarchy of site factors in ascertaining the need for and type of left-turn lane. In order of importance these factors are:

* midblock left-turn demands
* peak period through traffic volume
* abutting land use
* accident experience

* sight distance
* average highway speed (AHS)
* number of through lanes
* block spacing
* pedestrian movements
* public preference
* abutting retailers preference

(6) Survey showed a preference for CTWLTML's in areas of
* demand for midblock left turns
* peak through traffic volume
* strip commercial land use
* AHS   30 mph
* four through lanes
* "long" block spacing
* drivers and abutting retailers preference

(7) Survey showed a preference for raised COWLTML's in areas of restricted sight distance and pedestrian crossing demand.

(8) Flush COWLTML's were ranked by those surveyed between CTWLTML's and raised COWLTML's

(9) Other operational advantages of CTWLTML's over COWLTML's are:
* continuous access
* flexible storage
* variable deceleration lengths
* emerging use of median area

(10) Raised COWLTML's have the advantage of
* greater control over vehicle movements
* reduced potential conflicts
* more positive separation of traffic
* pedestrian refuge

(11) Accident reductions have been observed for typical installation of CTWLTML and raised and flushed COTLTML
* CTWLTML - on the order of 35%

* raised COTLTML - on the order of 50 to 70 percent
* flush COWLTML - on the order of 15 percent (urban) to 50 percent (rural)

Field Study and Data Analysis

From the survey the location of median turn lanes throughout the state were identified. The selection criteria used to identify the study sites were the specific median left-turn-lane type (emphasis on CTWLTML), availability of accident records and traffic data, speed limts, geometric configuration, land uses, driveway locations, traffic signals, section lenths and block numbers, and other related data. Follow-up field studies were made on selected locations and sufficient field data were collected to identify accident characteristics which enabled the development of site variable relationships. For the accident study, an initial list of more than 60 site variables were used in the data analysis process. The application of regression analysis to the prediction of accident rates required the selection of an equation which provided the "best" estimate of rates. The best dependent variable for predicting accident rates on CTWLTML sections was the number of accidents per mile. The accident rate per mile equation also provided logical independent variables which consistently demonstrated relationships to accidents. These independent variable were weekday ADT, number of signals per mile, number of driveways per mile, and city size. The "average" accident per mile rate for the CTWLTML sites (including intersection accidents) was found to be 77.9 accidents per mile. The predictive equation is not recommended for other lane types since the model would render meaningless and misleading conclusions.

In the operational study phase, emphasis was placed on short blocks, offset intersections, typical CTWLTML, and raised and flush COWLTML. Survey and observation sites were selected for their characteristics, which included abutting land use, driveways location, lane widths, traffic conflicts, and erratic movements. Lateral placement of the vehicle in the left-turn median lane, as well as entering and maneuvering distances, was collected and analyzed using one-way analysis of variance method. In the lateral placement study, four types of analysis were performed on (1) lane widths, (2) pavement markings, (3) types of median-turn lane, and (4) location of the raised island. For the entrance distance, a study was made on four areas: (1) entrance distance during peak and off-peak periods, (2) entrance distance at midblock and intersections, (3) entrance distance behavior for different types of pavement markings, and (4) entrance distance behavior for different types of through lanes. The maneuvering distance portion of the study was concerned with the same general locations and configurations as the entering distance study.

Findings

The data analysis provided many interesting relationships concerning the characteristics and patterns of accidents and operationas aspects of CTWLTML's and raised and flush COWLTML's.

The following represents a summary of the study findings regarding the accident analysis:

(1) As discovered in the literature review, left-turn lanes are used under a large variety of conditions.

(2) Comparisons of general accident statistics for raised COWLTML sites and CTWLTML sites reveal common and similar patterns by hour of day, number of vehicles involved, and severity.

(3) Raised COWLTML sites have a greater proportion of intersection and intersection related accidents than CTWLTML sites - 75 percent and 55 percent for raised COTLTML sites and CTWLTML sites, respectively. CTWLTML sites have a higher proportion of driveway and non-intersection accidents.

(4) The major factors contributing to accidents on CTWLTML and raised COWLTML sites are unsafe speeding and failing to yield right-of-way, which are 56 percent and 24 percent of the two vehicle cases for CTWLTML sites and raised COWLTML sites, respectively. Following too closely is a contributing factor to 42 percent of the two vehicle accidents for raised COWLTML sites, compared to 14

percent for CTWLTML sites. The analysis of factors contributing to accidents illustrates the effects of greater freedom of movement allowed by CTWLTML's to allow continuous access to abutting property.

(5) An analysis of factors related to accidents on the study sites found that the percentage of cases involving driveway maneuvers on CTWLTML sites was twice that of raised COWLTML sites. Both CTWLTML sites had only small percentages of midblock accidents involving vehicles slowing or stoppint to make left-turns.

(6) The regression analysis found that accident equations improved as midblocks were combined into homogeneous sections and as intersection accidents were included in accident rate calculations.

(7) Separation of the regression analysis sites by lane type also improved the equations and eliminated many problems encountered with combined runs involving residual patterns when plotted against the dependent variables.

(8) The best dependent variable for estimation purposes was found to be the <u>number of accidents per mile</u>.

(9) Little success was found in predicting accident severities or damage measures.

(10) The most consistently important independent variables for prediction of accidents and rates are <u>weekday ADT</u>, <u>number of signals</u> (or signals per mile), <u>number of driveways</u> (or driveways per mile), and <u>city size</u>. Secondary variables were vehicle-miles, percent commercial land use, and the parking existence dummy variable.

(11) Independent variables notably absent from the equations were related to lane widths plus speed limits.

(12) A "best" predictive equation was selected and a table was developed illustrating the effects of the independent variables on the number of accidents per mile on CTWLTML sites.

In regard to the operational analysis the following findings were recorded:

Lateral Placement

(1) The photographic technique adopted for the data collection proved to be effective and economical. However, the degree of accuracy depends on the quality imposed in data collection and reduction.

(2) In reference to CTWLTML, lane widths of 11 feet and 12 feet have no significant adverse effect on traffic operations; but lane widths of approximately 15 feet or more created some confusion among drivers.

(3) In reference to a flush COWLTML, lane widths of 10 ft 6 in. to 12 ft 6 in. showed no significant operational variation.

(4) In reference to raised COWLTML, lane widths of 8 ft 6 in. to 10 ft 6 in. showed a significant variation.

(5) Standard CTWLTML markings and white single line button markings were interpreted differently by drivers.

(6) Use of paint or buttons for delineation showed some operational variation in terms of driver response and vehicle positioning.

(7) A raised COWLTML with paint markings and a flush COWLTML with 12-inch diameter metallic buttons on both sides of the lane were comparable in terms of vehicle queueing in the lane.

(8) There were significant differences between CTWLTMLs and flush COWLTMLs with 12-inch diameter metallic buttons on both sides of the lane.

(9) In a raised COWLTML, drivers tend to position the vehicle away from the raised barrier.

Entrance Distance

(1) Traffic volume, especially the left-turn and the adjacent through lane traffic volume, has a significant effect on entrance distance.

(2) Entrance distances to left-turns at midblock and at intersection approaches are different.

(3) The type of lane delineations has a significant effect on entrance distance.

(4) Entrance distance varies with the number of through lanes.

(5) There is a wide range of entrance distances on CTWLTMLs. The majority of drivers observed entered the CTWLTML 150-250 feet from the intersection. Very few drivers entered the lane less than 100 feet from the intersection.

Maneuvering Distance

(1) Although there exists a range of maneuvering distances, a large number of observed drivers completed the left-turn entry in 50 feet.

(2) Traffic volume and the numer of through lanes were found to influence maneuvering distance.

(3) Maneuvering distances are shorter at midblock than at intersection approaches.

Conclusions and Recommendations

The study findings suggest a wide range of guidelines for considerations by highway designs and traffic engineers. The guidelines refer to urban arterials and are recommended for use in addition to standard traffic engineering practice. These guidelines should, however, provide a higher level of user confidence and a basis for comparing information gained from other sources.

CTWLTMLs are an effective and efficient means of providing an enhanced level of service on many urban arterials. They are especially effective in locations of strip commercial development and frequent driveway openings experienceing moderate left-turn demand. Raised and flush COWLTMLs are effective at major intersections experienceing high left-turn demands.

CTWLTML lane widths and posted speed limits of the urban arterial were found to be adequately accounted for in standard practice by highway designers and traffic engineers. In other words, a minimum of an 11-ft lane with a desirable 12-ft requirement for CTWLTML facilities is recommended. Any lane width over 15 ft was found to create some driver confusion regardless of the speed of the through traffic or the legal speed limit. Therefore, the following provides a summary of recommended guidelines found in this study for left-turn median lanes.

(1) Existing site conditions should be carefully inventoried and assessed when considering left-turn lane improvements or installations. The findings of this or any other study should only be considered as guides, not warrants, for left-turn lane improvements or installations.

(2) Tables 2.4 and 2.5 should be used for estimating improvements in accident rates due to left-turn channelization at individual intersections.

(3) Tables 2.6 and 2.7 should be used as general guides for consideration of access control techniques.

(4) Existing accident locations, contributing factors, and related factors should be used as guides in determining potential effectiveness of left-turn lane types.

(5) Table 5.10 and the equation developed for estimation of accidents per mile on four lane CTWLTML sites should be used as guides for determining the potential effectiveness of a CTWLTML.

In general, CTWLTMLs provide for an increased flexibility such as the inherent characteristic of additional storage space for short blocks. The fear of conflicts and a resultant high increase in accidents after implementation are unfounded. In fact, most "anticipated" conflicts rarely occur and when or if they occur are handled with typical driver judgement. It was observed that the signing and pavement marking procedures in the MUTCD Sections 3B-12 and 2B-17 (as amended in Volumes I-VIII) are effective in informing drivers of CTWLTML operations. It is the opinion of the authors that signing contributes marginally to driver awareness and that pavement markings (lane delineation and symbol messages) are mandatory. Speed limits imposed on many CTWLTML locations serve little purpose because of the characteristic use of the facility.

In regard to raised or flush COWLTML, no significant driver conflict problems were observed. Adequate storage space for the left-turn queue was the primary design element creating any concern.

In reference to raised lane markers (e.g. ceramic or metallic buttons) there are other minor observations of interest:

(1) Half-inch high square buttons and three-inch high, eight-inch diameter buttons installed at the intersection approach to separate opposing traffic were not observed to be very effective in prohibiting left turns from the opposing traffic.

(2) Twelve-inch metallic buttons are effective in separating through lane traffic and left-turn lane traffic. However, several disadvantages are: (a) the buttons are difficult to maintain and clean, (b) they can create hazards to the motorcyclists, and (c) they may force motorists that entered the left-turn lane by mistake to turn at the intersection. Few vehicles were observed returning to the through lane at the intersection and few vehicles entered the left-turn lane by crossing through the space between buttons.

In conclusion the CTWLTML, as appreciated by most practitioners is an excellent TSM-type of option. It is recommended for use where an assessment using standard traffic engineering practices and these guidelines suggest it as an effective alternative.

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APPENDIX A

ACCIDENT STUDY AND

STATISTICAL DESCRIPTION OF REGRESSION VARIABLES

TABLE A.1. VARIABLE MEANS AND STANDARD DEVIATIONS FOR 212 MIDBLOCKS, ALL LANE TYPES, WITHOUT INTERSECTION ACCIDENTS

VARIABLE	MEAN	STANDARD DEVIATION
SITEID	3,1109057E+03	1.4242483E+03
XNTAM	4,5000000E+00	4.7670870E+00
XNLTAM	6,1792453E-01	1.0258551E+00
XTAMMM	6,9144481E+02	6.3104551E+02
XLTMMM	9,3917928E+01	1.5898132E+02
XAMM	5,0077471E+01	5.1448239E+01
XLTMM	6,2535113E+00	9.6605788E+00
SIM	1,6599575E-01	2.6183349E-01
CRM	5,5592017E+03	3.4055228E+03
ADSM	1,3967524E+00	9.2195862E-01
VEHMT	1,7972639E+03	1.0369369E+03
XLTYP1	8,8679245E-01	3.1759627E-01
XLTYP3	8,4905660E-02	2.7940100E-01
SECLEN	1,0316038E-01	5.9220151E-02
DCBD	3,1773585E+00	2.0664452E+00
CISZ	2,1709528E+05	1.1985239E+05
DIOSXM	2,0017893E+01	1.4851480E+01
THRUSL	3,7688679E+01	5.4717945E+00
XLTSL	2,4056604E-01	4.2843887E-01
XLTWI	1,1823113E+01	1.7187518E+00
XTLWI	4,9326887E+01	5.1068752E+00
ATHWI	1,2054677E+01	9.7410791E-01
XNTHL	4,1037736E+00	4.4464684E-01
XCHLT	2,9245283E-01	6.7405516E-01
AS1	2,7358491E-01	4.4685354E-01
AS2	2,6415094E-01	4.4192356E-01
PKG1	1,6037736E-01	3.6782420E-01
PKG2	1,3679245E-01	3.4444143E-01
XCTWT	1,3207547E-01	3.6624058E-01
TWADT	1,8398255E+04	6.7046467E+03
XLEG1	4,6226415E-01	4.9975403E-01
XLEG2	4,6698113E-01	5.0008941E-01
TNDR	5,5943396E+00	4.6839006E+00
TNDRM	5,6572949E+01	3.6097306E+01
PAC	4,7882649E+01	3.3043614E+01
XNAC	3,9811321E+00	4.0797294E+00
XNACM	4,1590717E+01	3.5259535E+01
PSER	8,7179071E+00	1.5510228E+01
XNSER	7,0754717E-01	1.3627890E+00
XNSERM	7,2564321E+00	1.4531612E+01
PPUB	9,5789038E+00	1.8496630E+01
PRES	1,6169011E+01	2.3597703E+01
XNRES	6,0849057E-01	1.7799631E+00
XNRESM	4,9046712E+00	1.1491223E+01
PVAC	1,6366981E+01	2.3780178E+01
XNIR	1,5188679E+00	2.4133559E+00
A-IR	2,9811321E+00	3.1905700E+00

TABLE A.2. VARIABLE MEANS AND STANDARD DEVIATIONS FOR 76 SECTIONS, ALL LANE TYPES, WITH INTERSECTION ACCIDENTS

VARIABLE	MEAN	STANDARD DEVIATION
SITEID	3.0930341E+03	1.5211649E+03
XNTA	2.8802632E+01	2.0146808E+01
XNLTA	7.1315789E+00	5.4487726E+00
XTAMM	1.1243970E+03	6.9460334E+02
XLTMM	2.8723767E+02	2.3105094E+02
XAM	7.7093047E+01	6.2034664E+01
XLTM	1.9264717E+01	1.7632336E+01
SI	2.0229211E-01	1.1814223E-01
CR	4.4303177E+03	1.8060844E+03
ADS	1.7020408E+00	3.6490255E-01
VEHMI	7.4540058E+03	3.7138449E+03
XLTYP1	8.1578947E-01	3.9023160E-01
XLTYP3	1.4473684E-01	3.5417312E-01
SECLEN	4.4421053E-01	1.8764692E-01
DCBD	3.7763368E+00	2.1653524E+00
CISZ	2.4805658E+05	1.0743953E+05
DIOSZ	1.8927909E+01	1.3591381E+01
THRUSL	3.6381579E+01	7.3302426E+00
XLTSL	1.9736842E-01	4.0065735E-01
XLTWI	1.1613158E+01	1.3507866E+00
XTLWI	4.9471053E+01	7.8821962E+00
ATHWI	1.2011842E+01	1.0459785E+00
XNTHL	4.1315789E+00	6.8004128E-01
XCHLT	1.5789474E+00	2.8764013E+00
XNAS1	1.9868421E+00	2.3180073E+00
XNSIG	1.0657895E+00	9.1411927E-01
PKG1	2.2368421E-01	4.1948172E-01
PKG2	1.9736842E-01	4.0065735E-01
XCTWT	5.1315789E-01	1.2805563E+00
TWADT	1.7575453E+04	6.8719646E+03
XN3L	3.0921053E+00	2.5201991E+00
XN4L	2.4078947E+00	1.8774283E+00
TNDR	2.1236842E+01	1.5018094E+01
TNDRM	5.0161814E+01	3.0810221E+01
PAC	4.2271900E+01	2.9811284E+01
XNAC	1.4736842E+01	1.3061259E+01
XNACM	3.5915236E+01	2.8729800E+01
PSER	7.7060697E+00	9.7153555E+00
XNSER	2.5789474E+00	3.1927550E+00
XNSERM	6.0452382E+00	7.6140831E+00
PPUB	1.0771020E+01	1.6232800E+01
XNPUB	1.0263158E+00	1.5997807E+00
XNPUBM	2.1823487E+00	3.3950162E+00
PRES	2.2690845E+01	2.4724862E+01
XNRES	2.6052632E+00	5.3218517E+00
XNRESM	5.3889026E+00	9.6305997E+00
PVAC	1.4886184E+01	1.7565326E+01
XNSPM	2.0161105E+00	2.1796536E+00
PPLT	3.7609650E+01	4.5389129E+01
XNIR	1.6684211E+01	1.2524334E+01
LGTNDR	1.2113409E+00	3.6126182E-01

TABLE A.3. VARIABLE MEANS AND STANDARD DEVIATIONS FOR 76 SECTIONS, ALL LANE TYPES, WITHOUT INTERSECTION ACCIDENTS

VARIABLE	MEAN	STANDARD DEVIATION
SITEID	3.0930341E+03	1.5211649E+03
XNTA	1.7223684E+01	1.4322568E+01
XNLTA	2.4078947E+00	2.5569650E+00
XTAMM	6.4118206E+02	4.0160369E+02
XLTMM	9.5975638E+01	1.0022761E+02
XAM	4.5658445E+01	4.0474377E+01
XLTM	6.4314329E+00	7.2033299E+00
SI	1.8611842E-01	1.6756863E-01
CR	3.1010321E+03	1.2842954E+03
ADS	1.6260526E+00	5.1357776E-01
VEHMI	7.4540058E+03	3.7138449E+03
XLTYP1	8.1578947E-01	3.9023160E-01
XLTYP3	1.4473684E-01	3.5417312E-01
SECLEN	4.4421053E-01	1.8764692E-01
DCRD	3.7763368E+00	2.1653524E+00
CISZ	2.4805658E+05	1.0743953E+05
DIOSZ	1.8927909E+01	1.3591381E+01
THRUSL	3.6381579E+01	7.3302426E+00
XLTSL	1.9736842E-01	4.0065735E-01
XLTWI	1.1613158E+01	1.3507866E+00
XTLWI	4.9471053E+01	7.8821962E+00
ATHWI	1.2011842E+01	1.0459785E+00
XNTHL	4.1315789E+00	6.8004128E-01
XCHLT	1.5789474E+00	2.8764013E+00
XNAS1	1.9868421E+00	2.3180073E+00
XNSTG	1.0657895E+00	9.1411927E-01
PKG1	2.2368421E-01	4.1948172E-01
PKG2	1.9736842E-01	4.0065735E-01
XCTWT	5.1315789E-01	1.2805563E+00
TWADT	1.7575453E+04	6.8719646E+03
XN3I	3.0921053E+00	2.5201991E+00
XN4I	2.4078947E+00	1.8774283E+00
TNDR	2.1236842E+01	1.5018094E+01
TNDRM	5.0161814E+01	3.0810221E+01
PAC	4.2271900E+01	2.9811284E+01
XNAC	1.4736842E+01	1.3061259E+01
XNACM	3.5915236E+01	2.8729800E+01
PSFR	7.7060697E+00	9.7153555E+00
XNSFR	2.5789474E+00	3.1927550E+00
XNSFRM	6.0452382E+00	7.6140831E+00
PPUB	1.0771020E+01	1.6232000E+01
XNPUB	1.0263158E+00	1.5997807E+00
XNPUBM	2.1823487E+00	3.3950162E+00
PRES	2.2690845E+01	2.4724862E+01
XNRES	2.6052632E+00	5.3218517E+00
XNRESM	5.3889026E+00	9.6305997E+00
PVAC	1.4886184E+01	1.7565326E+01
XNSPM	2.0161105E+00	2.1796536E+00
PPLT	3.7609650E+01	4.5389129E+01
XNIR	5.1052632E+00	6.2473012E+00
LGTNDR	1.2113409E+00	3.6126182E-01

TABLE A.4. VARIABLE MEANS AND STANDARD DEVIATIONS FOR 11 SECTIONS, RAISED COWLTML'S, WITH INTERSECTION ACCIDENTS

VARIABLE	MEAN	STANDARD DEVIATION
SITEID	3.2280509E+03	9.3024578E+02
XNTA	3.2636364E+01	2.7576340E+01
XNLTA	7.6363636E+00	6.0211748E+00
XTAMM	1.0580863E+03	5.7697905E+02
XLTMM	2.8374749E+02	2.3385240E+02
XAM	8.0319991E+01	7.4658518E+01
XLTM	1.9362773E+01	1.6607217E+01
SI	1.8257273E-01	7.5962531E-02
CR	4.0661576E+03	9.8237708E+02
ADS	1.7238818E+00	4.2280766E-01
VEHMI	7.9631618E+03	4.0810363E+03
LGTNDR	1.1522134E+00	3.6199712E-01
SECLEN	4.4545455E-01	1.8451903E-01
DCRD	4.7319545E+00	1.2746828E+00
CISZ	3.8458182E+05	4.9877306E+04
DIOSZ	1.2173691E+01	3.0490369E+00
THRUSL	3.8636364E+01	3.2333490E+00
XLTWI	1.0945455E+01	6.9190120E-01
XTLWI	5.4481818E+01	9.4859705E+00
ATHWI	1.1768336E+01	1.8088828E+00
XNTHL	4.7272727E+00	1.0090500E+00
XCHLT	6.1818182E+00	2.7136021E+00
XNAS1	1.4545455E+00	1.5724908E+00
XNSIG	7.2727273E-01	7.8624539E-01
PKG1	7.2727273E-01	4.6709937E-01
PKG2	7.2727273E-01	4.6709937E-01
TWADT	1.8346330E+04	8.4453289E+03
XN3L	2.1818182E+00	2.3159526E+00
XN4L	2.2727273E+00	1.5550504E+00
TNDR	1.7636364E+01	1.3477928E+01
TNDRM	4.3597327E+01	3.4293148E+01
PAC	4.4016291E+01	3.8902308E+01
XNAC	1.3909091E+01	1.3118342E+01
XNACM	3.4272291E+01	3.3812481E+01
PSER	3.8717818E+00	4.6398112E+00
XNSER	1.0000000E+00	1.0954451E+00
XNSERM	2.2933545E+00	2.6418163E+00
PPUB	8.2690182E+00	1.5962019E+01
XNPUB	2.7272727E-01	4.6709937E-01
XNPUBM	7.8876364E-01	1.3688023E+00
PRES	1.7734809E+01	1.7476535E+01
XNRES	2.3636364E+00	3.6952057E+00
XNRESM	6.0495000E+00	1.0610876E+01
PVAC	2.5143736E+01	2.6468716E+01
XNSPM	1.5683636E+00	1.9091671E+00
PPLT	2.7272727E+01	4.6709937E+01
XNTR	2.0909091E+01	1.8063524E+01

TABLE A.5. VARIABLE MEANS AND STANDARD DEVIATIONS FOR 11 SECTIONS, RAISED COWLTML's, WITHOUT INTERSECTION ACCIDENTS

VARIABLE	MEAN	STANDARD DEVIATION
SITEID	3.2280509E+03	9.3024578E+02
XNTA	2.0000000E+01	2.2022716E+01
XNLTA	2.0909091E+00	2.8793939E+00
XTAMM	6.8820360E+02	4.9463993E+02
XLTMM	9.1644591E+01	1.3372330E+02
XAM	4.9028764E+01	5.6078105E+01
XLTM	5.3561364E+00	7.5395984E+00
SI	1.0056364E-01	1.0268441E-01
CR	3.1470040E+03	8.2670432E+02
ADS	1.5467364E+00	4.0331648E-01
VEHMI	7.9631618E+03	4.0810363E+03
LGTNDR	1.1522134E+00	3.6199712E-01
SECLEN	4.4545455E-01	1.8451903E-01
DCRD	4.7319545E+00	1.2746828E+00
CISZ	3.8458182E+05	4.9877306E+04
DIOSZ	1.2173691E+01	3.0490369E+00
THRUSL	4.8636364E+01	3.2333490E+00
XLTWI	1.0945455E+01	6.9190120E-01
XTLWI	5.4481818E+01	9.4859705E+00
ATHWI	1.1708336E+01	1.8088828E+00
XNTHL	4.7272727E+00	1.0090500E+00
XCHLT	6.1818182E+00	2.7136021E+00
XNASI	1.4545455E+00	1.5724998E+00
XNSTG	7.2727273E-01	7.8624539E-01
PKG1	7.2727273E-01	4.6709937E-01
PKG2	7.2727273E-01	4.6709937E-01
TWAOT	1.8346330E+04	8.4453289E+03
XN3I	2.1818182E+00	2.3159526E+00
XN4I	2.2727273E+00	1.5550504E+00
TNDP	1.7636364E+01	1.3477928E+01
TNDPM	4.3597327E+01	3.4293148E+01
PAC	4.4016291E+01	3.8902308E+01
XNAC	1.3909091E+01	1.3118342E+01
XNACM	3.4272291E+01	3.3812481E+01
PSFP	3.8717818E+00	4.6398112E+00
XNSFR	1.0000000E+00	1.0954451E+00
XNSFRM	2.2933545E+00	2.6418163E+00
PPUB	8.2690182E+00	1.5962019E+01
XNPUB	2.7272727E-01	4.6709937E-01
XNPUBM	7.8876364E-01	1.3688023E+00
PRES	1.7734809E+01	1.7476535E+01
XNRES	2.3636364E+00	3.6952057E+00
XNRESM	6.0495000E+00	1.0610876E+01
PVAC	2.5143736E+01	2.6468716E+01
XNSPM	1.5683636E+00	1.9091671E+00
PPLT	2.7272727E+01	4.6709937E+01
XNTP	8.2727273E+00	1.1507310E+01

TABLE A.6. VARIABLE MEANS AND STANDARD DEVIATIONS FOR 62 SECTIONS, CTWLTML'S, WITHOUT INTERSECTION ACCIDENTS.

VARIABLE	MEAN	STANDARD DEVIATION
SITEID	2.9924294E+03	1.5746842E+03
XNTA	1.6903226E+01	1.3040554E+01
XNLTA	2.5000000E+00	2.5719164E+00
XTAMM	6.5627986E+02	3.9474109E+02
XLTMM	1.0007111E+02	9.6416831E+01
XAM	4.6036545E+01	3.8409796E+01
XLTM	6.7839452E+00	7.3191495E+00
SI	2.0526290E-01	1.7456671E-01
CR	3.1933323E+03	1.3649218E+03
ADS	1.6161274E+00	5.3127188E-01
VEHMI	7.3752350E+03	3.7633300E+03
LGTNDR	1.2194508E+00	3.8271698E-01
SECLEN	4.3951613E-01	1.9163171E-01
DCBD	3.6933710E+00	2.2590495E+00
CISZ	2.2012097E+05	9.5783854E+04
DIOSZ	2.0764918E+01	1.4321242E+01
THRUSL	3.7177419E+01	4.4001647E+00
XLTSL	2.4193548E-01	4.3175144E-01
XLTWI	1.1729032E+01	1.4352000E+00
XTLWI	4.9461290E+01	5.7961648E+00
ATHWI	1.2085215E+01	8.7869905E-01
XNTHL	4.0967742E+00	4.3266909E-01
XCHLT	6.2903226E-01	1.5495517E+00
XNAS1	2.0483871E+00	2.4119064E+00
XNSTG	1.1290323E+00	9.3183885E-01
PKG1	1.4516129E-01	3.5513905E-01
PKG2	1.1290323E-01	3.1905797E-01
XCTWT	6.2903226E-01	1.3935904E+00
TWADT	1.7615125E+04	6.7317318E+03
XN3I	3.2419355E+00	2.5394299E+00
XN4I	2.3709677E+00	1.8837865E+00
TNDR	2.2225806E+01	1.5378737E+01
TNDRM	5.2380469E+01	3.0282045E+01
PAC	4.3770582E+01	2.7792899E+01
XNAC	1.5483871E+01	1.3158232E+01
XNACM	3.7697748E+01	2.7861633E+01
PSFR	7.9648355E+00	9.4958662E+00
XNSFR	2.9032258E+00	3.4054425E+00
XNSFRM	6.8211113E+00	8.1206019E+00
PPUB	9.9204145E+00	1.2333029E+01
XNPUB	1.1290323E+00	1.6839052E+00
XNPUBM	2.4080597E+00	3.6275724E+00
PRES	2.3219698E+01	2.5355733E+01
XNRES	2.3709677E+00	5.0578096E+00
XNRESM	4.7154984E+00	8.2168015E+00
PVAC	1.3280219E+01	1.5204387E+01
XNSPM	2.1134065E+00	2.2621425E+00
PPLT	3.8037635E+01	4.4777862E+01
XNIR	4.7096774E+00	4.8700729E+00

TABLE A.7. VARIABLE MEANS AND STANDARD DEVIATIONS FOR 62 SECTIONS, CTWLTML'S, WITH INTERSECTION ACCIDENTS

VARIABLE	MEAN	STANDARD DEVIATION
SITEID	2.9924294E+03	1.5746842E+03
XNTA	2.8274194E+01	1.9222740E+01
XNLTA	7.0000000E+00	5.5159976E+00
XTAMM	1.1426813E+03	7.3006027E+02
XLTMM	2.8693020E+02	2.3777433E+02
XAM	7.7866871E+01	6.1394508E+01
XLTM	1.9436842E+01	1.8327952E+01
SI	2.0982419E-01	1.2490878E-01
CR	4.5140237E+03	1.9499566E+03
ADS	1.6968177E+00	3.5659579E-01
VEHMI	7.3752350E+03	3.7633300E+03
LGTNDR	1.2194508E+00	3.8271698E-01
SECLEN	4.3951613E-01	1.9163171E-01
DCRD	3.6933710E+00	2.2590495E+00
CISZ	2.2012097E+05	9.5783854E+04
DIOSZ	2.0764918E+01	1.4321242E+01
THRUSL	3.7177419E+01	4.4001647E+00
XLTSL	2.4193548E-01	4.3175144E-01
XLTWI	1.1729032E+01	1.4352000E+00
XTLWI	4.9461290E+01	5.7961648E+00
ATHWI	1.2085215E+01	8.7869905E-01
XNTHL	4.0967742E+00	4.3266909E-01
XCHLT	6.2903226E-01	1.5495517E+00
XNAS1	2.0483871E+00	2.4119064E+00
XNSIG	1.1290323E+00	9.3183885E-01
PKG1	1.4516129E-01	3.5513905E-01
PKG2	1.1290323E-01	3.1905797E-01
XCTWT	6.2903226E-01	1.3935904E+00
TWADT	1.7615125E+04	6.7317318E+03
XN3L	3.2419355E+00	2.5394299E+00
XN4L	2.3709677E+00	1.8837865E+00
TNDR	2.2225806E+01	1.5378737E+01
TNDRM	5.2380469E+01	3.0282045E+01
PAC	4.3770582E+01	2.7792899E+01
XNAC	1.5483871E+01	1.3158232E+01
XNACM	3.7697748E+01	2.7861633E+01
PSER	7.9648355E+00	9.4958662E+00
XNSER	2.9032258E+00	3.4054425E+00
XNSERM	6.8211113E+00	8.1206019E+00
PPUB	9.9204145E+00	1.2333029E+01
XNPUB	1.1290323E+00	1.6839052E+00
XNPUBM	2.4080597E+00	3.6275724E+00
PRES	2.3219698E+01	2.5355733E+01
XNRES	2.3709677E+00	5.0578096E+00
XNRESM	4.7154984E+00	8.2168015E+00
PVAC	1.3280219E+01	1.5204387E+01
XNSPM	2.1134065E+00	2.2621425E+00
PPLT	3.8037635E+01	4.4777862E+01
XNTP	1.6080645E+01	1.1601722E+01

APPENDIX B

OPERATIONAL ANALYSIS:

DATA COLLECTION METHODOLOGIES

APPENDIX B: OPERATIONAL ANALYSIS: DATA COLLECTION METHODOLOGIES

This appendix gives a brief description of the procedure on data collection for entrance distance, maneuvering distance, lateral placement volume, and conflict.

ENTRANCE DISTANCE

Entrance distance is the distance from an intersection where a vehicle enters the turn lane before making a left-turn maneuver. This applies to CTWLTML facilities since the COWLTML has specific openings provided for left-turn entry.

Ten 3-inch × 6-inch markers made out of poster board were laid 50 feet apart on top of the CTWLTML line. The markers were spaced from a location 500 feet from the stopping line of an intersection to a location 50 feet from the same stop line of the intersection. These markers were painted orange and were small to minimize influence on the driver's behavior. The details of the marking are shown in Fig B.1.

Two observers were used to collect the data, one for the first 250-foot section and the other for the remaining section. The observers stood at the sixth marker at the sidewalk, far enough away to avoid influencing the driver. The entrance distance was recorded when the left front wheel touched the CTWLTML line. A data sheet made in advance was used by the observer to record the observation and facilitate the estimate of distances between markers. Any entrance between two markers can be scaled easily and recorded by the observer in the data sheet. An example of this data sheet is shown in Fig B.2.

MANEUVERING DISTANCE

Maneuvering distance is the distance required for the left turn vehicle to fully enter the left-turn lane. It was estimated by recording on the data sheet the spot where the left front wheel touched the CTWLTML and the spot where the right rear wheel touched the CTWLTML. The distance between these spots is the maneuvering distance. The same two observers, markers, and forms were utilized for this data collection.

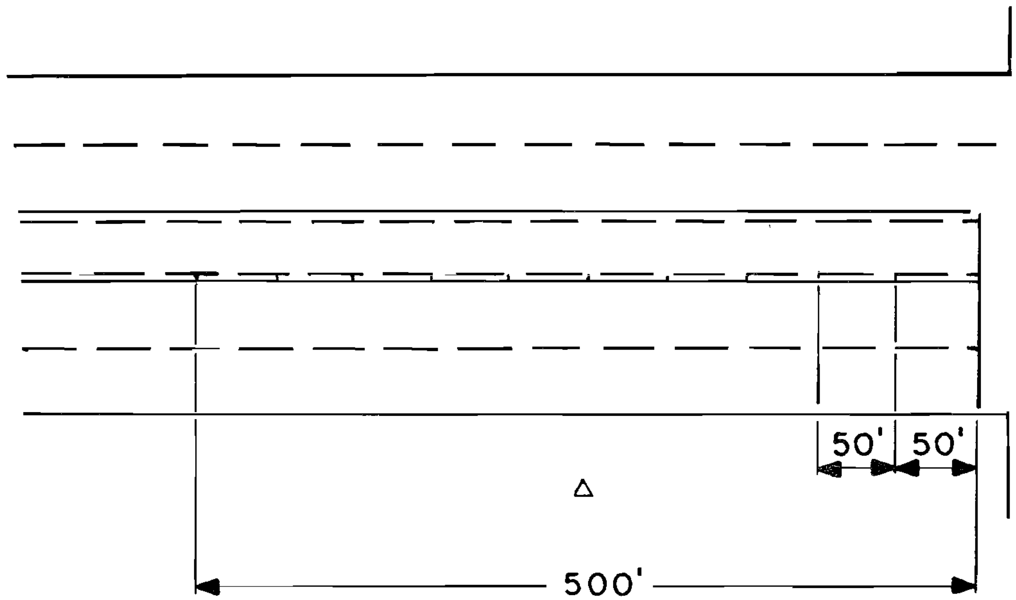


Fig B.1. Typical location of markers for obtaining entrance and maneuvering distances.

TIME	DISTANCE MEASUREMENT	Q L on LTL	Q L on TL	VEH BEH	TIME	DISTANCE MEASUREMENT	Q L on LTL	Q L on TL	VEH BEH

Fig B.2. Data sheet.

LATERAL PLACEMENT

Lateral placement is the position of the vehicle within a traffic lane. The methodology adopted is simply to use a movie camera and to make a still photograph of the vehicle on the reference line. Three known markers made out of raised traffic buttons were put on the reference line and used to adjust the data reduced from the film into real dimensions and, furthermore, determine the lateral deviation of the vehicle from the centerline of the lane.

Technique

The typical set-up at a site is shown in Fig B.3, in which the camera is set about 30 degrees from the center of the reference line. Three reference markers were put on the reference line and their exact positions were measured. A photograph of the vehicle was taken when both wheels of the vehicle were on the reference line. An average of 40 pictures were taken at each site and there is an allowable error of 3.8 inches at a 95 percent confidence level.

A projector with a frame control was used to reduce the data on a frame by frame basis. Each frame was projected on the wall, and a scale was laid along the reference line for recording all the necessary data. The three reference markers were recorded first and the centers of the wheels were used for determining the centerline of the vehicle in the lane. The lateral deviation was determined by finding the distance between the midpoint of the roadway and the centerline of the vehicle.

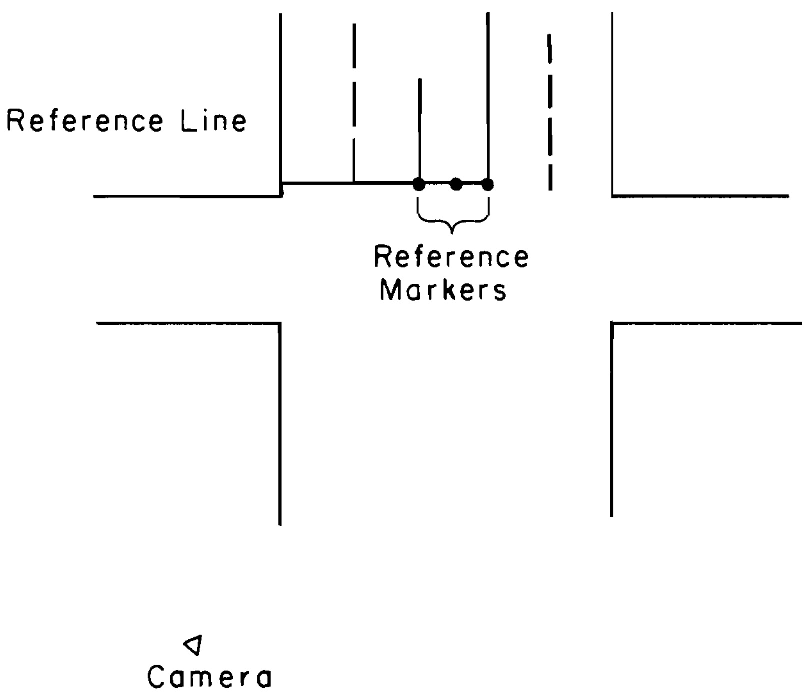


Fig B.3.   Typical site set-up.

Example

The three reference markers and the position of the right and left sides of the wheels are shown in Fig B.4. The positions of the reference markers measured at the site with respect to the right side marker were 72.5 inches and 145 inches; the same points measured from the film were 18 and 36.8 units.

Determination of scale factor:

$$y = ax + b$$
$$72.5 = 18a + b$$
$$145 = 36.8a + b$$
$$a = 0.00466$$
$$b = 4.1117$$

$$y = -0.00466x + 4.1117$$

where

y = scale factor

x = data point on film

Determination of the centerline of the vehicle:

Position of the wheel = [scale factor] [position of the wheel on film]

$$RW'' = [(-0.00466)\ (9.1) + 4.1117]\ [9.1]$$
$$= 37.03$$
$$LW'' = [(-0.00466)\ (25.0) + 4.1117]\ [25.0]$$
$$= 99.88$$

Centerline of the vehicle, CL_{veh} :

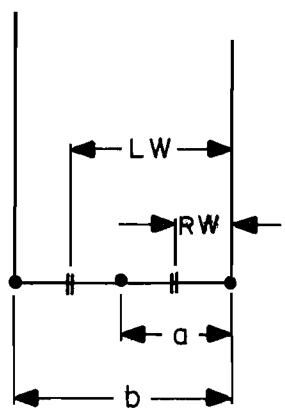
$$CL_{veh} = \frac{LW'' - RW''}{2} + RW''$$

$$= \frac{99.88 - 37.03}{2} + 37.03$$

$$= 68.46$$

Lateral deviation of the vehicle, LD :

$$LD = CL_{lane} - CL_{veh}$$
$$= 72.5 - 68.46$$
$$= 4.04''$$



Position of Reference Markers and Centers of the Wheels

	Film	Actual
a	18	72.5"
b	36.8.	145"
RW	9.1	RW"
LW	25.0	LW"

Fig B.4. Data acquired at the site and from the film.

Accuracy of Technique

A controlled situation was set up in a parking lot, and the same procedure was carried out to determine the accuracy of the technique The camera was positioned at three different angles: 15°, 30°, and 45° from the middle reference marker. The results are shown graphically in Figs B.5, B.6, and B.7, in which the x axis is the position of the wheels in front of or behind the reference line, and the y axis is the error term obtained by subtracting the film data from the data measured at the site.

An average error of 1.3 inches was recorded at three different positions, and all three graphs indicated simultaneously that a minimum of error occurred when the vehicle was right on the top of the reference line, and there was a trend to a larger error when the vehicle was in front of the line (after crossing the line) than when it was behind the line.

VOLUME

A clipboard counter was used to record the through lane volume, left turn volume, and opposite volume. This volume count was made simultaneously with the distance data collection. The volume count is used as a relative descriptor of the site congestion. Earlier volume count included only the straight through volume, left-turn volume, and opposite direction straight through volume. In the later volume data collection, the volume count consisted of the total volume before the intersection, including the right and left-turn volume from the minor street into the study section.

CONFLICT DATA

Conflict data include any frictions caused by vehicles turning left over the study section. They can also be misuses or erratic movements at the site. Only the peak period was observed since the higher volume would normally generate more conflicts.

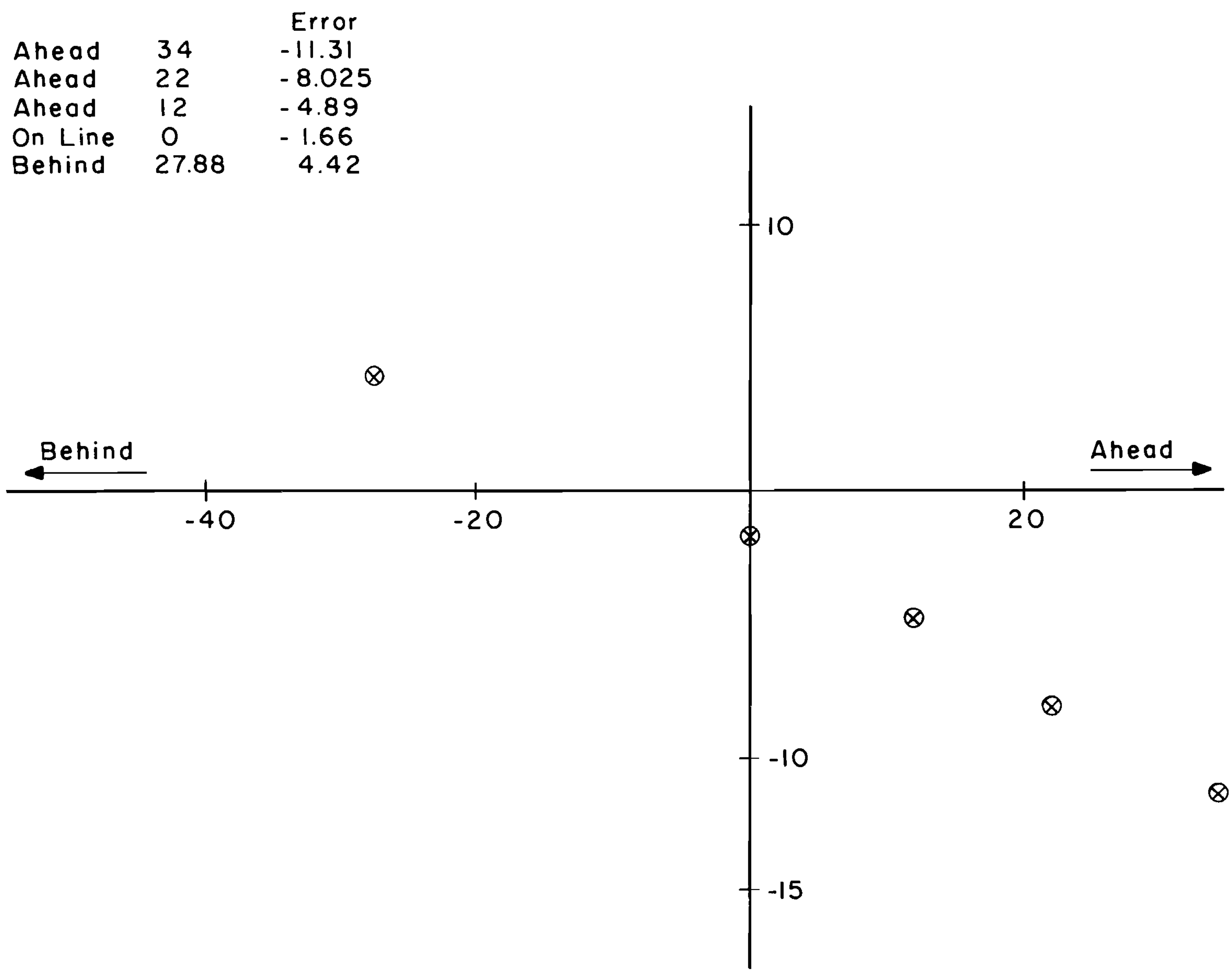


Fig B.5. Error observed at 15°.

		Error
Ahead	24.125	-13.75
0	0	-1.24
Behind	26.125	12.53

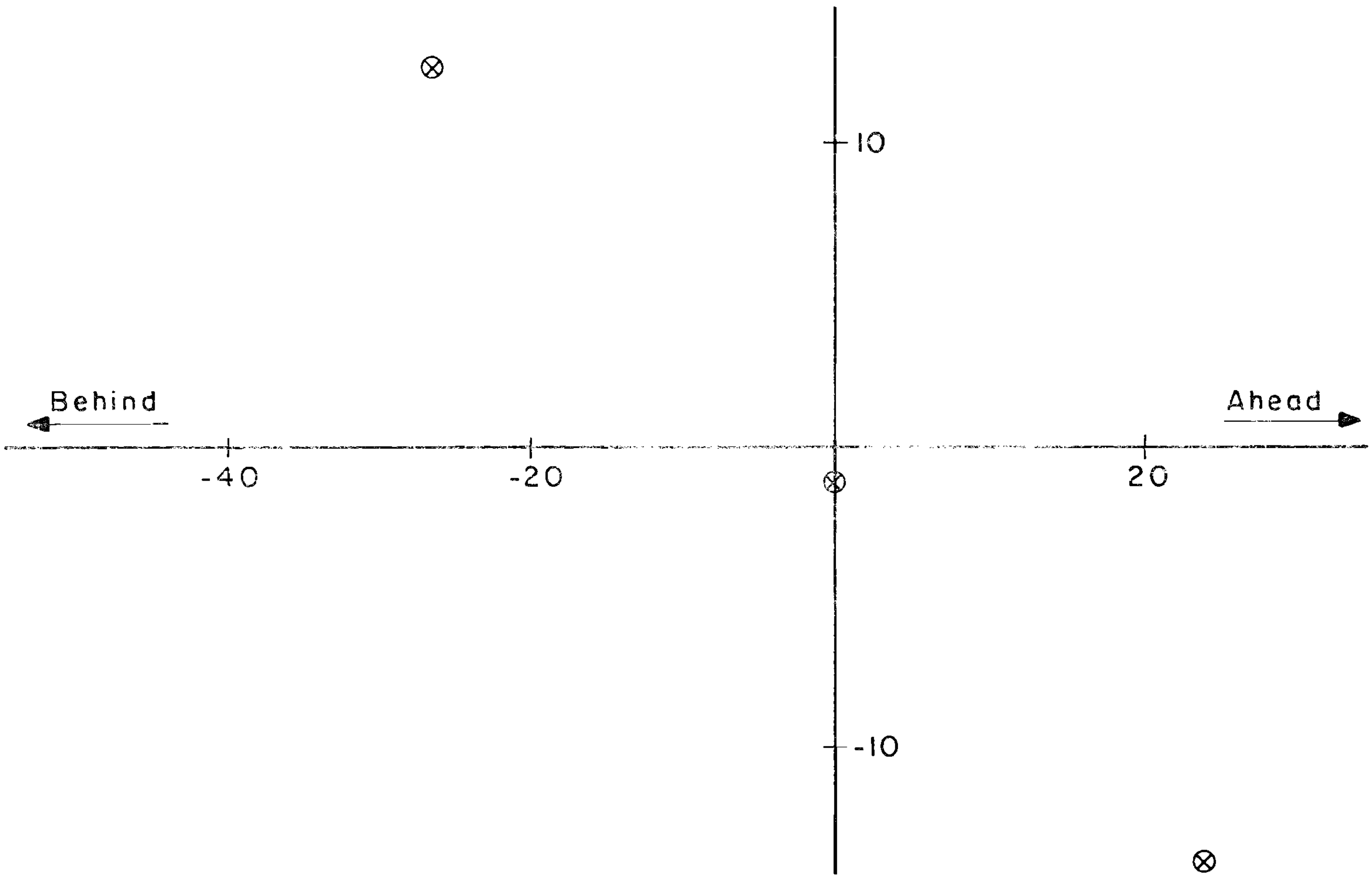


Fig B.6. Error observed at 30°.

		Error
Ahead	24.125	-24
0	0	-1.23
Behind	27.88	-24.71

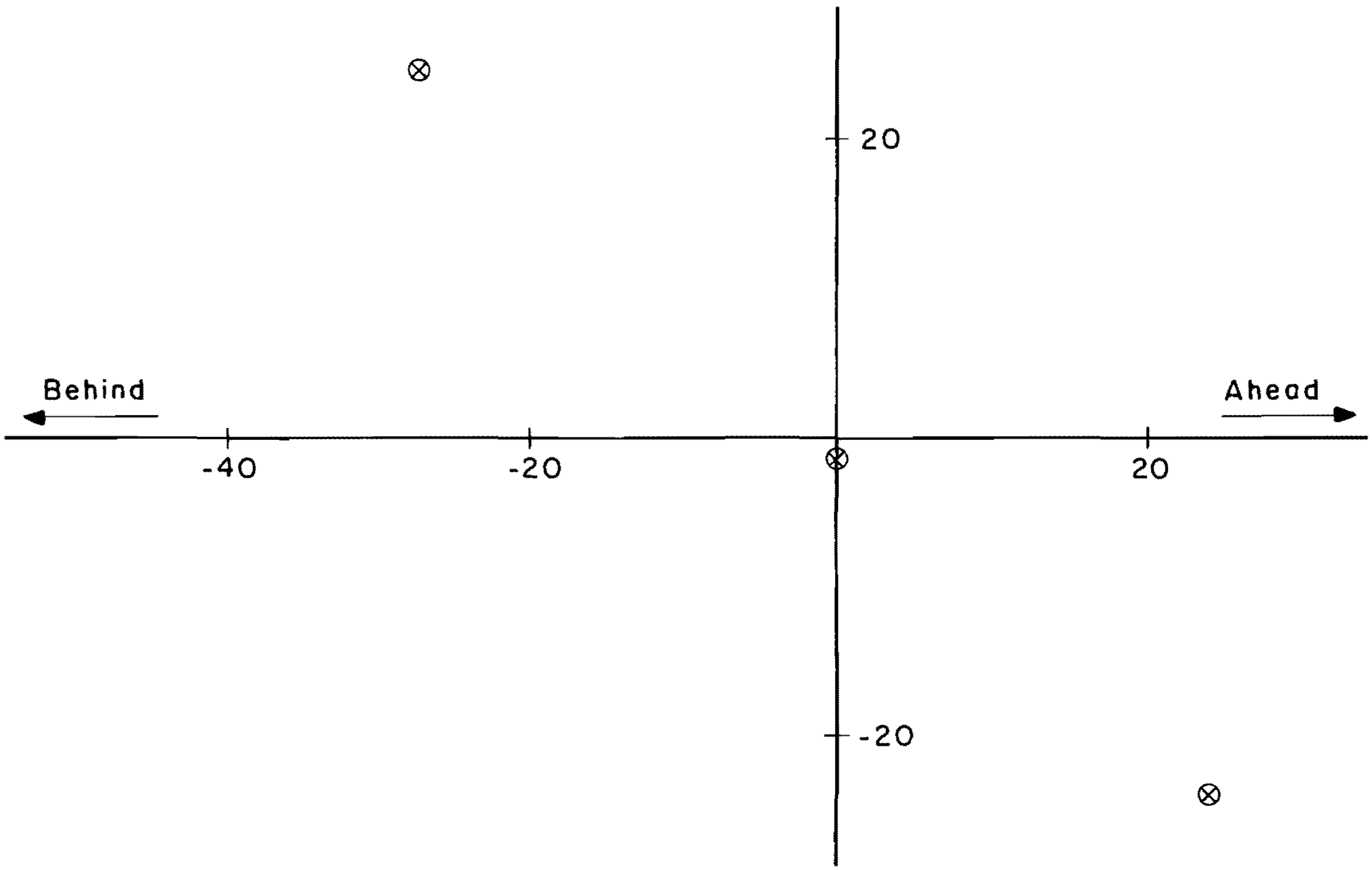


Fig B.7. Error observed at 45°.

Theoretically, five types of conflicts were identified as pertinent to the operation of CTWLTML. They are shown in Fig B.8 and listed below:

(1) head-on conflict,

(2) conflict between vehicle in CTWLTML and a left-turn vehicle from a minor street that just enters the CTWLTML,

(3) conflict between a vehicle in CTWLTML and a vehicle that starts to enter the CTWLTML from the through lane,

(4) conflict between a left-turn vehicle from the through lane (without using the CTWLTML) and the straight-through vehicle, and

(5) conflict between the vehicle in CTWLTML and the left-turn vehicle from the through lane.

In a flush COWLTML, fewer types of conflicts are possible since it allows fewer choices to the drivers. This factor can be considered as an advantage in terms of accident prevention, but, on the other hand, it can also be considered as a disadvantage in terms of accessibility. Possible types of conflicts for COWLTML are shown in Fig B.9 and listed below:

(1) conflict between a left-turn vehicle and the straight-through vehicle in the through lane,

(2) conflict between a left-turn vehicle in the left-turn lane and the left-turn vehicle from the opposite direction, and

(3) conflict between a left-turn vehicle and a straight-through vehicle in the opposite direction.

On a raised COWLTML, even fewer conflict types are possible since conflicts with the opposite stream of traffic are eliminated. The only possible type of conflict, shown in Fig B.10, is a conflict between a left-turn vehicle and a through vehicle in the through lane.

SUMMARY

A total of twenty sites were selected on the basis of land use, left turn facility, average daily traffic volume, post speed limit, and type of delineation. Various operational data were considered, and those adopted were conflicts, lateral placement of the vehicle within the left-turn lane, entrance distance, and maneuvering distance.

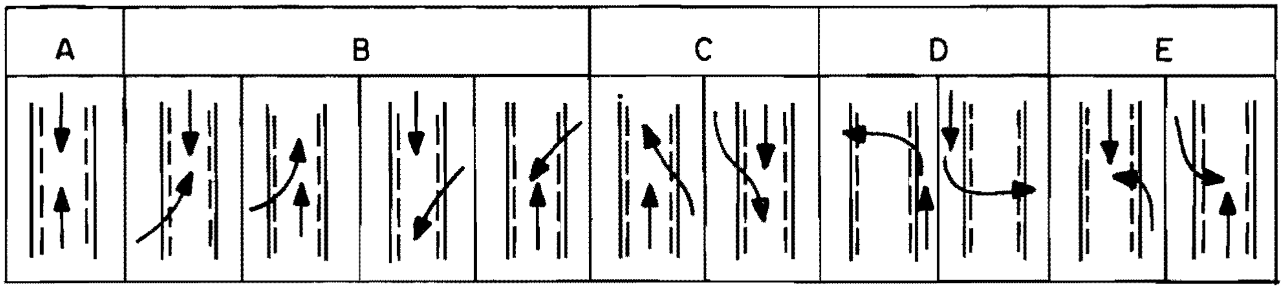


Fig B.8. Possible left-turn related conflicts on CTWLTML.

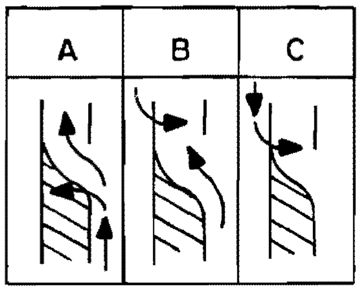


Fig B.9. Possible left-turn related conflicts on flush COWLTML.

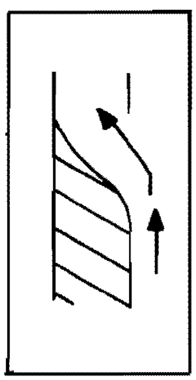


Fig B.10. Possible left-turn related conflicts on raised COWLTML.

APPENDIX C

OPERATIONAL ANALYSIS:

PRESENTATION OF DATA

FOR INDIVIDUAL CASE COMPARISONS

APPENDIX C: OPERATIONAL ANALYSIS: PRESENTATION OF DATA FOR INDIVIDUAL CASE COMPARISONS

This Appendix presents the data collected at the sites. Since different sets of data were collected at various types of left-turn facilities, the data are presented on a case by case basis. A total of 20 sites were studied.

FORMAT OF DATA

On all but two of the continuous two-way left-turn median facilities the data are presented in the following manner: (1) site characteristics, (2) personal observations, (3) lateral placement, (4) entrance distance, and (5) maneuvering distance.

On all the channelized one-way left-turn median facilities, only lateral placement was collected since entrance and maneuvering distances were restricted by the facility design. The lateral placement data are followed by a personal observation if there were any unusual or erratic movements at the site. The final presentation on COWLTML includes (1) site characteristics, (2) lateral placement, and (3) personal observations.

DATA PRESENTATION

Site characteristics consist of the exact location, the traffic volume during the study period, the average daily traffic, pavement markings, the type of facility, and the lane width. A diagram or photograph was made to record the adjacent land use and the site. Personal observations consist of traffic conflicts and any erratic movements observed at the site. Lateral placement is illustrated in two graphs. One graph shows the average vehicle displacement within the left-turn lane, and a bar chart shows the frequency diagram expressed in percent of observation in 10-inch increments from the center line of the left-turn lane. Entrance distance is illustrated by frequency diagrams expressed in percent of observations in 50-foot increments from the intersection during the period of observation. Maneuvering distance is shown in a similar manner, but in 20-foot increments.

<u>5th and 6th Streets and Lamar (Austin)</u>

<u>Site Characteristics</u>. The site is a short block between 5th and 6th Streets on Lamar Blvd. It is a five-lane facility with a continuous two-way median left-turn lane in the center. The average daily traffic is 31,110 and the volumes during the time of the data collection are shown in Table C.1.

The intersections are approximately 400 feet apart with protected left-turn signals for left-turn movements. The posted speed limit is 35 mph, and the markings are dashed white lines with white buttons (3-inch diameter) on through lanes and left-turn lanes. Yellow square buttons were installed before both intersections, separating the left-turn lane from the through lane. The width of the left-turn lane at 5th and Lamar is 10 feet 10 inches, and the one at 6th and Lamar is 10 feet 6 inches. The through lanes range in width from 10 feet 4 inches to 10 feet 10 inches. The land use at the site includes an automobile dealer, auto repair shops, and auto equipment shops (Fig C.1).

<u>Personal Observation</u>. During both the morning peak and offpeak periods, the highest left-turn volume was at the intersection of 5th and Lamar (East bound). The queue length in that left-turn lane was backed up approximately half the total length of the CTWLTML. However, no conflicts were observed during these periods.

It was also observed that there were several vehicles and pedestrians traveling across the five-lane facility at midblock. These midblock crossings created little difficulty for the through traffic since the signals at 5th and 6th Streets were coordinated so well that gaps were available for such crossings. The only problem during these periods was the midblock left-turners into the automobile dealer, which created a hazard to the following left-turn intersection vehicles. However, this problem was not as serious during these periods as in the evening peak period. During the evening peak period, the left-turn volume at the intersection of 6th and Lamar increased tremendously, and one signal cycle was incapable of clearing the left turn queue, which kept increasing and sometimes extended to the intersection of 5th and Lamar. As a result of this

TABLE C.1. VOLUME DATA AT 5th & LAMAR AND AT 6th & LAMAR

Fifth Street AM Peak Period

	Lane 1	Lane 2	Lane 3a	Lane 3b	Lane 4	Lane 5
7:40	18	17	11	25	47	45
7:45	27	25	10	29	74	63
7:50	18	16	10	15	63	47
7:55	17	10	12	14	57	46
8:00	32	27	13	27	76	63
8:05	16	14	10	18	52	41
8:10	18	21	10	14	53	37
8:15	28	26	11	18	43	42
8:20	23	22	9	14	41	38
8:25	23	23	7	13	39	29
Total	220	201	103	187	545	451
Rate*	66	60	31	56	164	135

Fifth Street Offpeak Period

	Lane 1	Lane 2	Lane 3a	Lane 3b	Lane 4	Lane 5
10:00	35	32	18	19	34	32
10:05	16	24	15	11	26	25
10:10	20	26	18	14	30	31
10:15	30	27	13	15	39	37
10:20	22	25	18	14	34	23
10:25	29	33	17	9	28	30
10:30	28	19	17	11	37	31
10:35	28	25	19	9	29	30
10:40	27	34	17	12	28	23
Total	235	245	152	114	285	262
Rate	78	82	51	38	95	87

(continued)

TABLE C.1. (Continued)

Fifth Street PM Peak Period

	Lane 1	Lane 2	Lane 3a	Lane 3b	Lane 4	Lane 5
4:20	40	54	24	16	40	32
4:25	65	65	15	23	35	46
4:30	50	50	12	21	33	26
4:35	65	79	13	20	36	48
4:40	74	74	10	23	37	40
4:45	67	77	14	24	40	48
4:50	80	88	13	24	34	36
4:55	48	46	13	12	28	41
5:00	88	80	9	23	34	39
5:05	63	75	8	18	44	46
5:10	71	68	7	20	31	47
5:15	84	76	10	32	40	53
5:20	70	65	8	14	33	38
5:25	64	60	11	10	24	25
5:30	75	92	11	16	39	36
5:35	57	62	18	16	20	18
5:40	45	66	7	23	19	29
Total	1106	1177	203	335	567	648
Rate	195	208	36	59	100	114

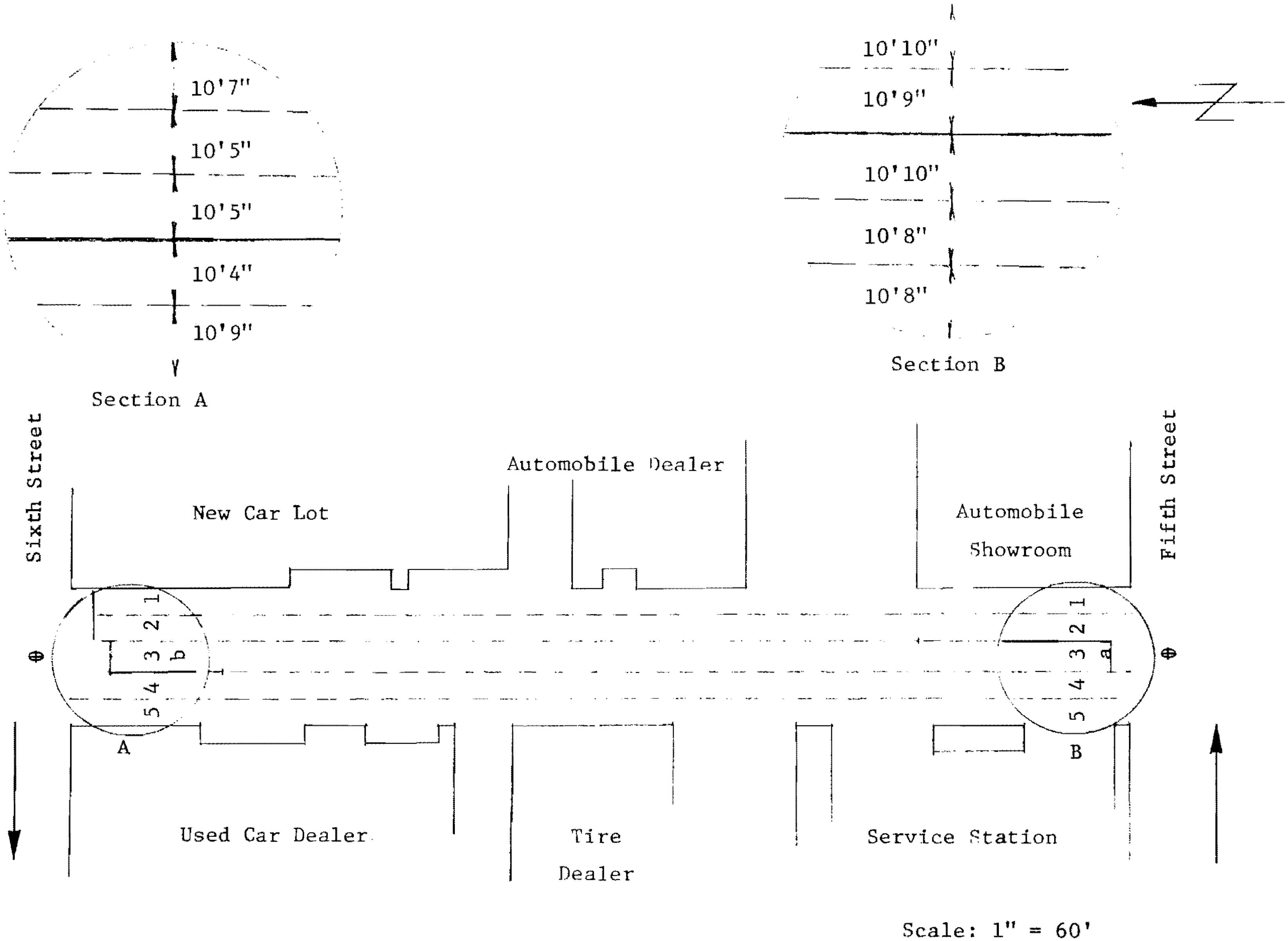


Figure C.1. Land use on Lamar between 5th and 6th - Austin, Texas queue, midblock left turns into the automobile dealership had difficulty in finding a suitable gap. The long wait for available gaps created a problem for the stationary left-turn vehicles, causing some to become impatient, move out of the CTWLTML to pass the midblock left-turn vehicle, and then reenter the left turn lane.

During the evening peak period, there was a higher demand for left turns at the intersection of 6th & Lamar than at the intersection of 5th & Lamar. The demand at 6th Street was so high that the queue sometimes ended up at the 5th Street intersection. As the queue length increased, the maneuvering distance became shorter. Sometimes vehicles entered the left-turn lane at the intersection of 5th & Lamar, leaving no space or just enough storage space for one vehicle at that intersection. One unique characteristic of this section was the change in demand for left-turn storage space during peak periods. When the queue backed up to the intersection of 5th & Lamar, only a few vehicles or sometimes none turned left at that intersection. On two occasions, this queue actually forced some vehicles to turn left from the through lane at the intersection (Fig C.2).

During the two hours of observation in the evening, there were two times when the queues at the intersections backed up to each other. These back-ups caused some hazards to the through lane traffic and paralyzed their operation (Fig C.3).

Lateral Placement. Lateral placement of vehicles at the approach to 5th Street is summarized in Fig C.4. The average displacement is 18.77 inches left of the center line of the left-turn lane.

Lateral placement at the approach to 6th Street is summarized in Fig C.5. The average displacement is 4.45 inches left of the center line of the left-turn lane.

Entrance Distances. Entrance distances at the approach to 5th Street and 6th Street are shown in three figures. The entrance distance during the morning peak period is summarized in Fig C.6, in which the average entrance distance at 5th & Lamar is 209.6 feet and at 6th & Lamar is 207.1 feet. These distributions divided this 400-foot block evenly into

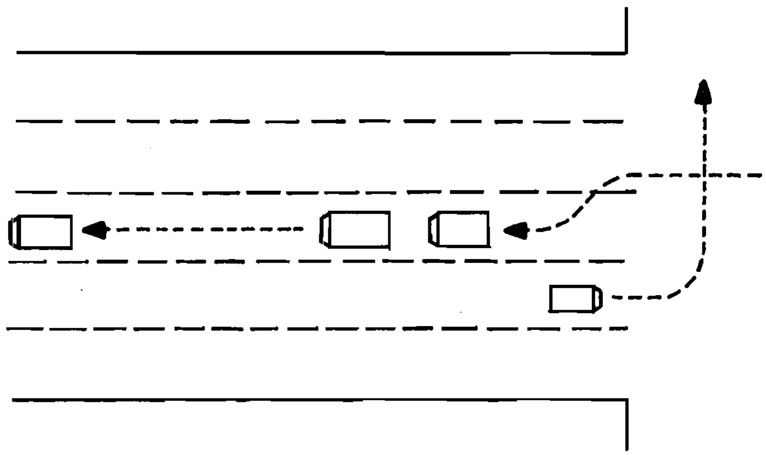


Fig C.2. Left turns from through lane.

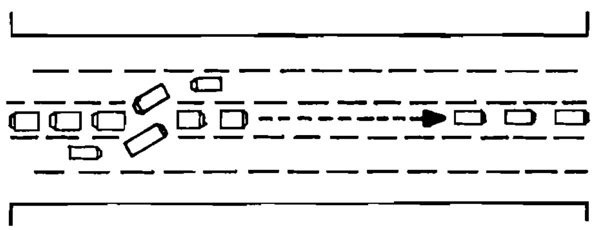


Fig C.3. Problem of insufficient storage space.

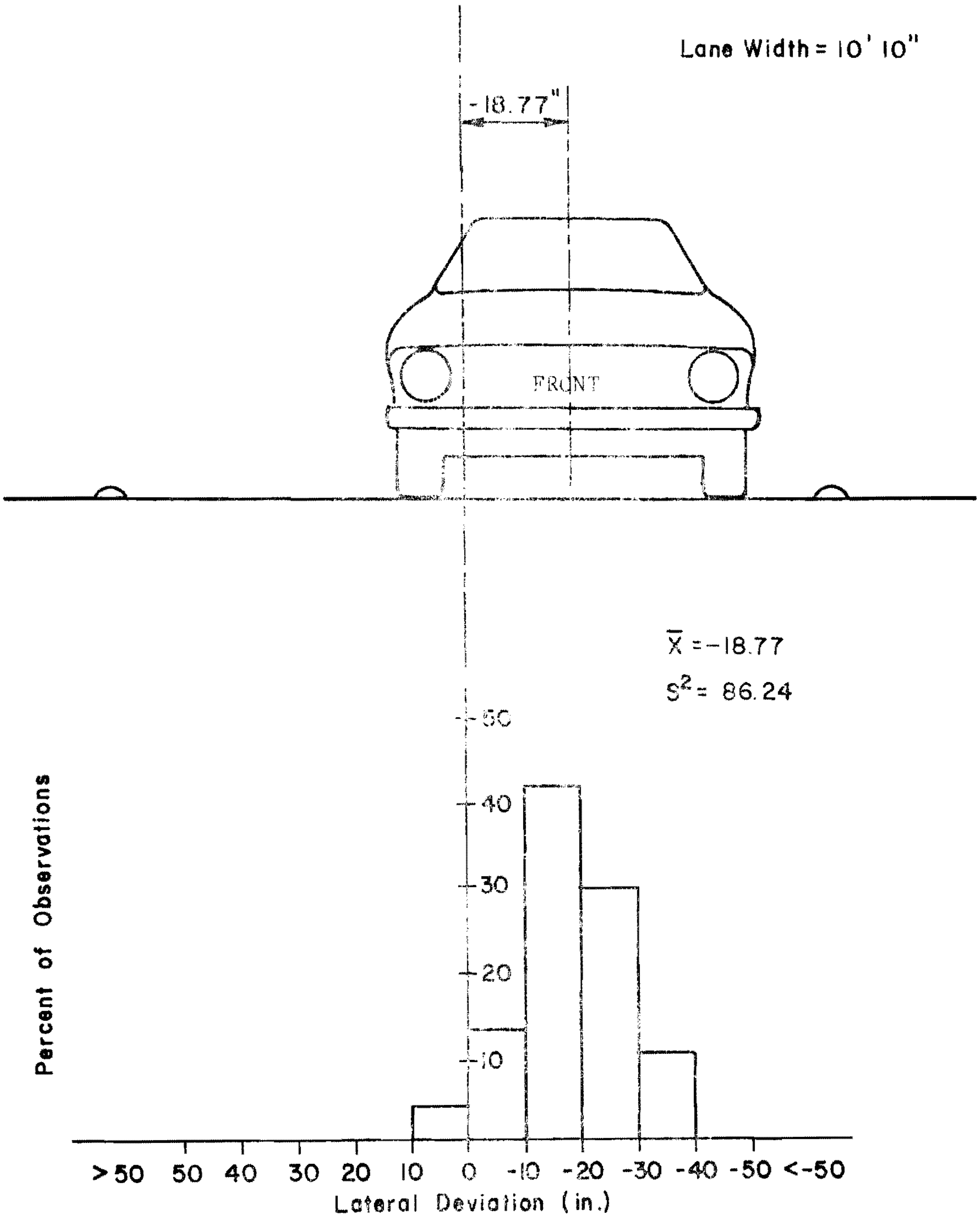


Fig C.4. Lateral placement at the intersection of 5th & Lamar Blvd.

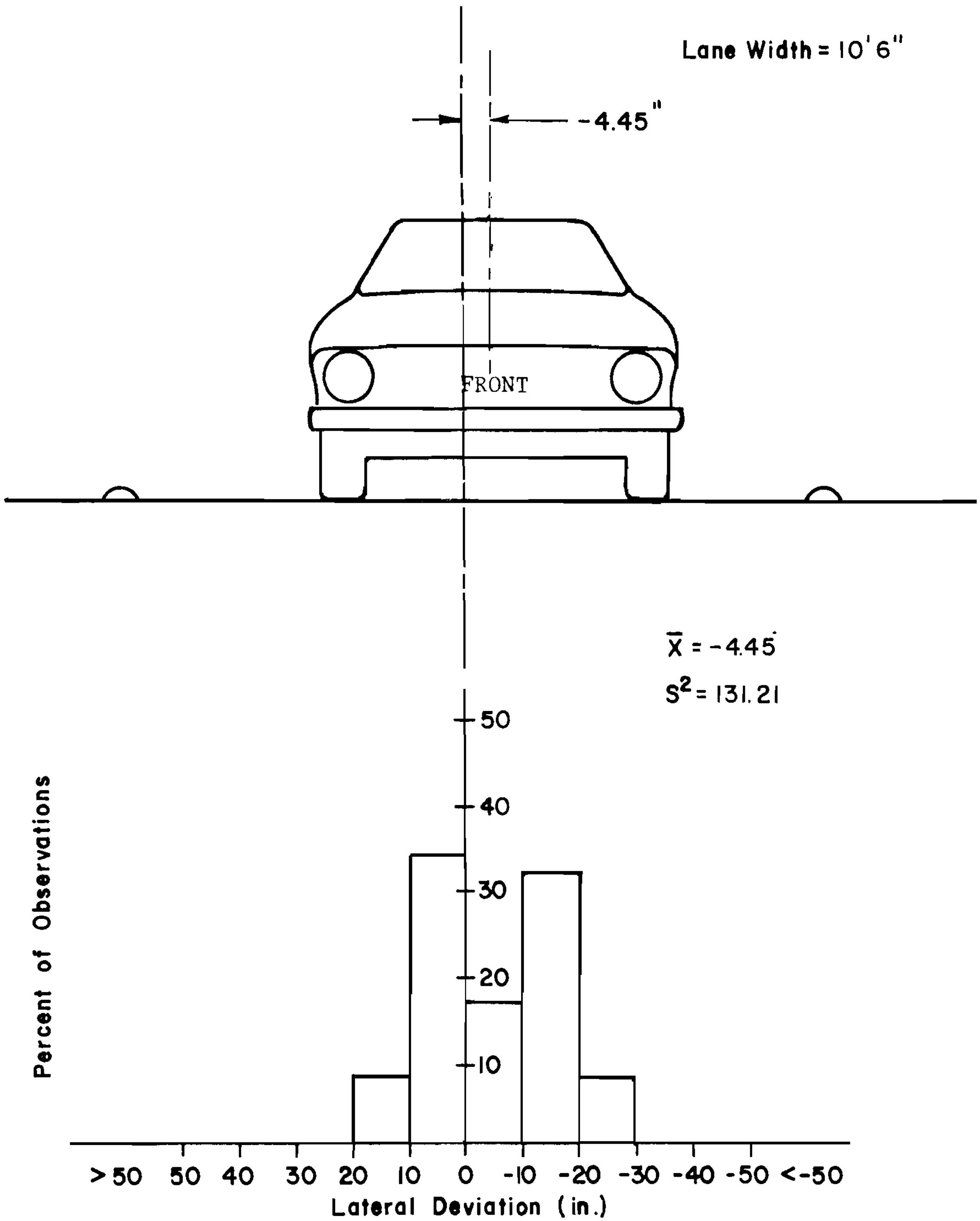
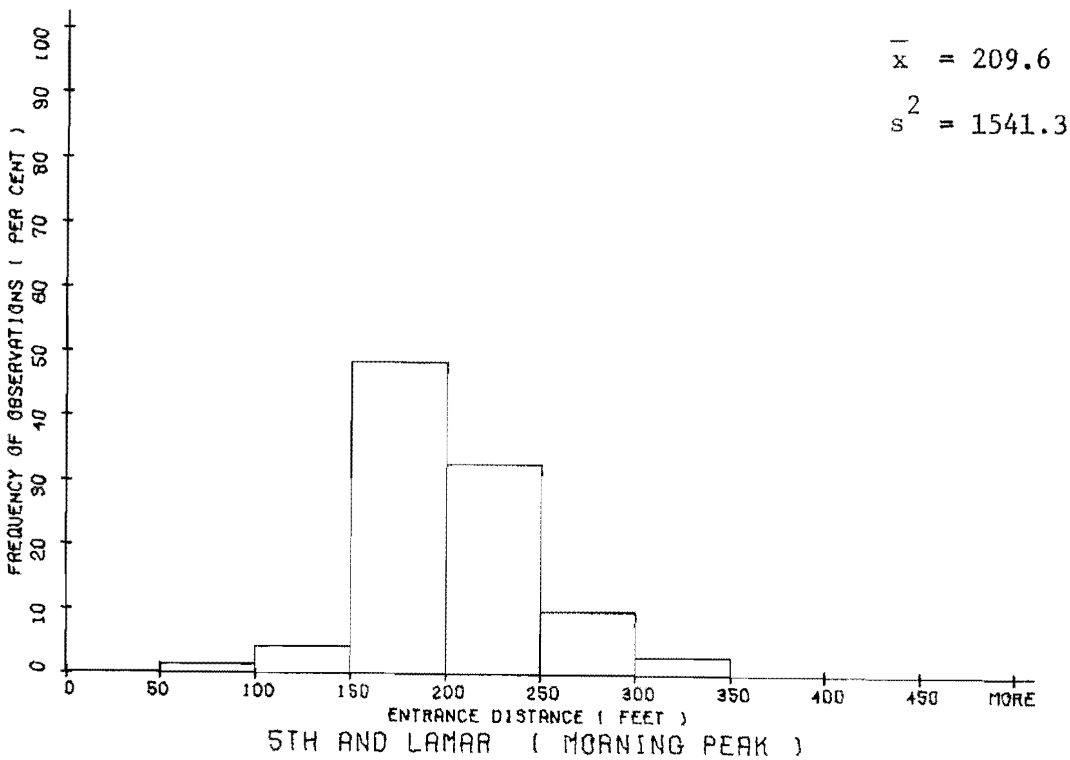
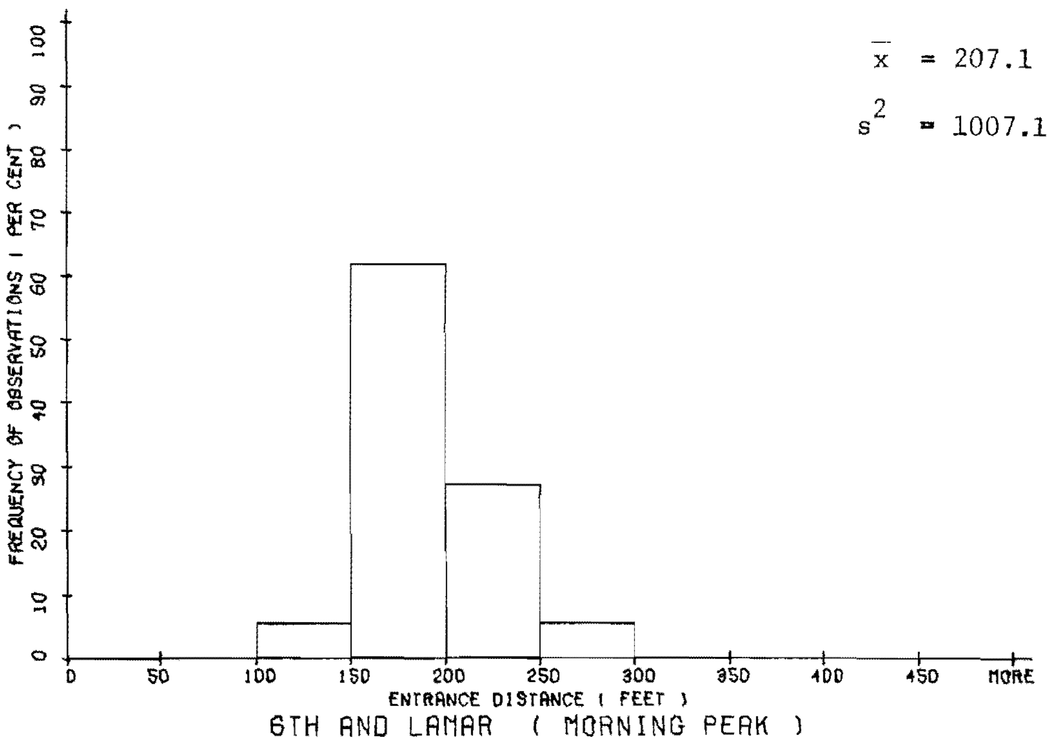


Fig C.5. Lateral placement at the intersection of 6th & Lamar Blvd.





C.6. Entrance distances at the 5th & Lamar and 6th & Lamar intersections during morning peak periods.

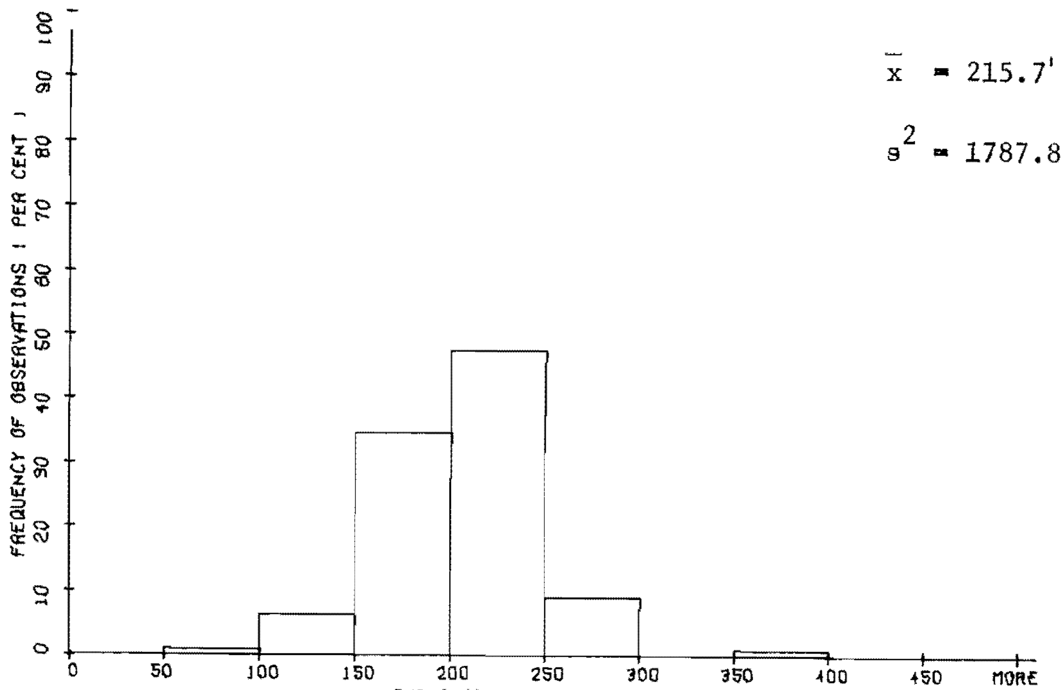
two back-to-back left-turn lanes. The entrance distance during the off-peak period is summarized in Fig C.7 where the entrance distance at 5th & Lamar has increased slightly and the entrance distance at 6th & Lamar stays the same. The entrance distance during the evening peak period is summarized in Fig C.8, which shows the entrance distance at 5th & Lamar has been reduced to 161.38 feet and the entrance distance at 6th & Lamar has increased to 263 feet. These graphs also show the queue length in the left-turn lane, where the queue length in the approach to 6th Street occupied half of the left-turn lane during this period, thus forcing vehicles to enter the left-turn lane 200-350 feet from the intersection.

Another useful characteristic of these graphs is the ability to estimate probable conflicts expected due to the entrance point of the vehicle. This can be done easily by placing one graph on the top of the other. The resulting overlapped bars are the percentage of probable conflicts during that period.

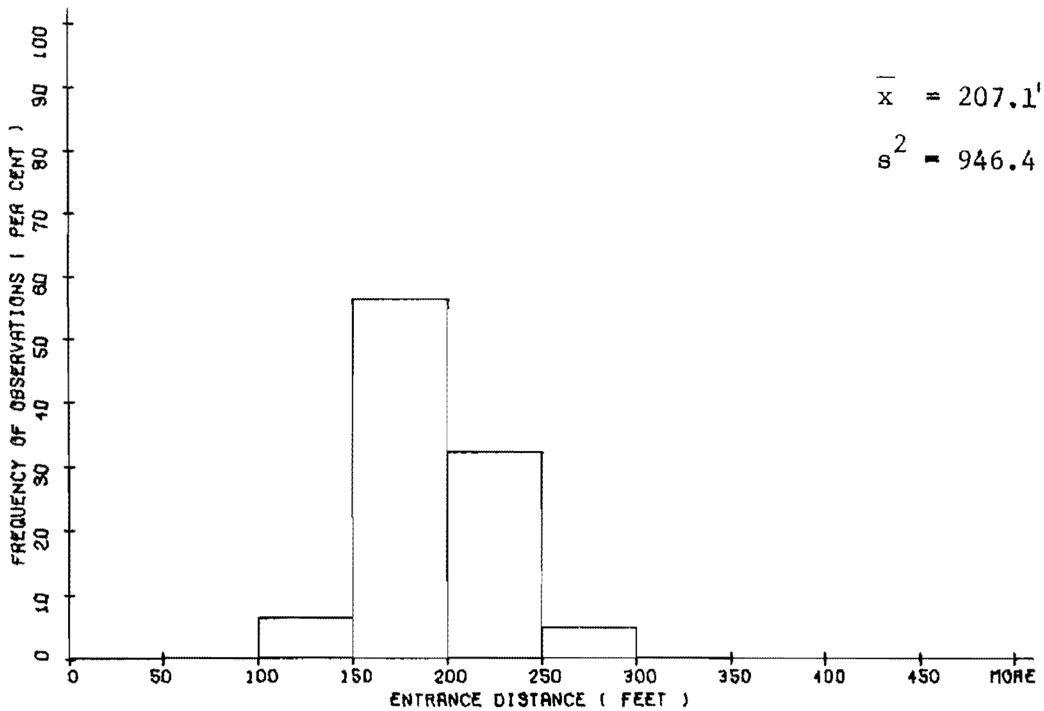
Maneuvering Distance. Maneuvering distances during the morning peak period at the approaches to 5th Street and 6th Street are summarized in Fig C.9 where the average displacements are 56.5 feet and 43.3 feet, respectively. Maneuvering distance during the offpeak period is summarized in Fig C.10, which shows results compatible with the morning peak period. Maneuvering distance during the evening peak period is summarized in Fig C.11, which shows the maneuvering distances were shorter at both approaches. These short maneuvering distances illustrate the effect of the short block situation and the queue length on the left-turn lane.

Burnet & Anderson (Austin)

Site Characteristics. The site is located on Burnet Road south of Anderson Lane. It is a five-lane facility with a continuous two-way median left-turn lane in the center. The average daily traffic is 22,570, and the volume during the time of data collection is shown in Table C.2.

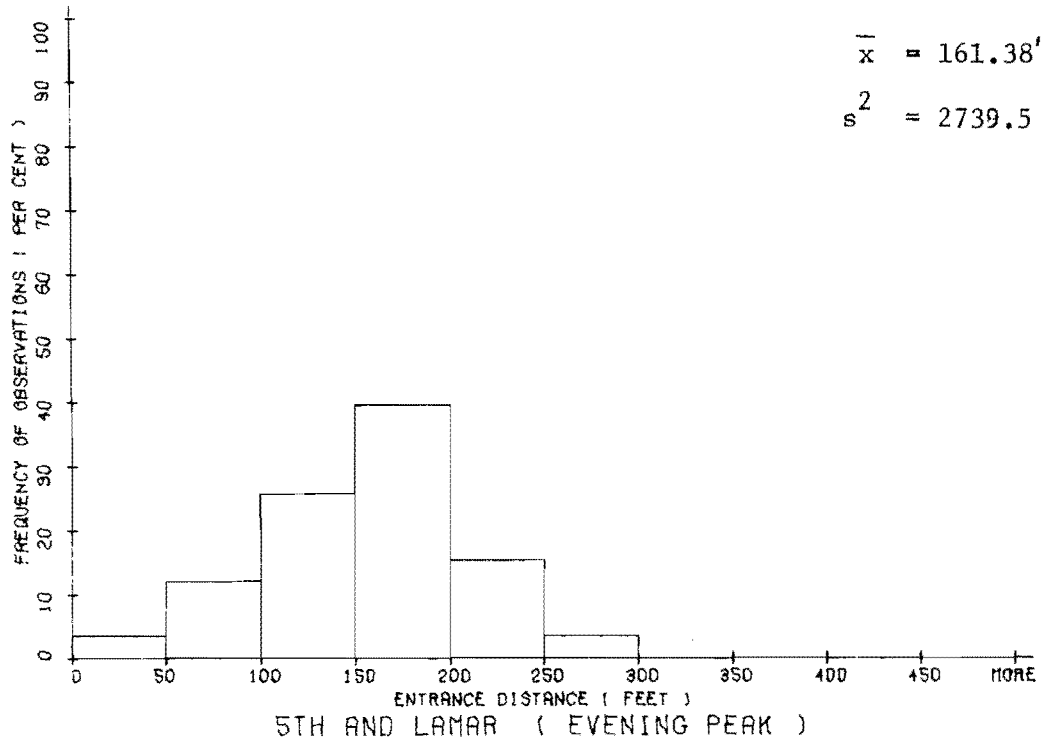


5TH AND LAMAR (OFFPEAK)



6TH AND LAMAR (OFFPEAK)

Fig C.7. Entrance distances at the 5th & Lamar and 6th & Lamar intersections during offpeak periods.



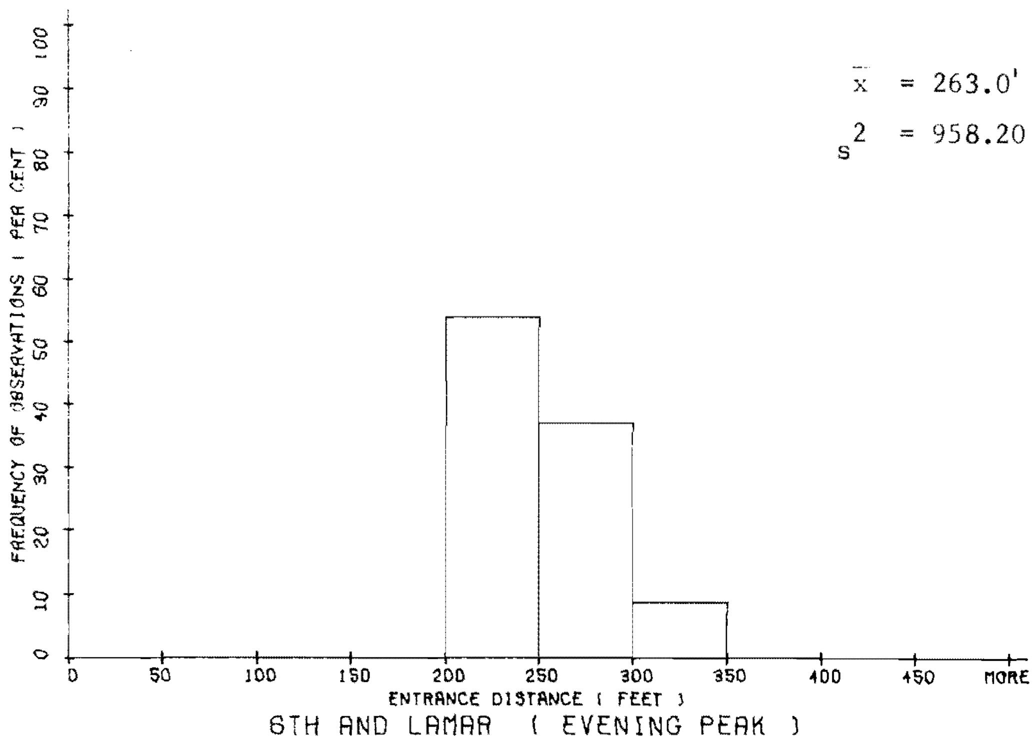
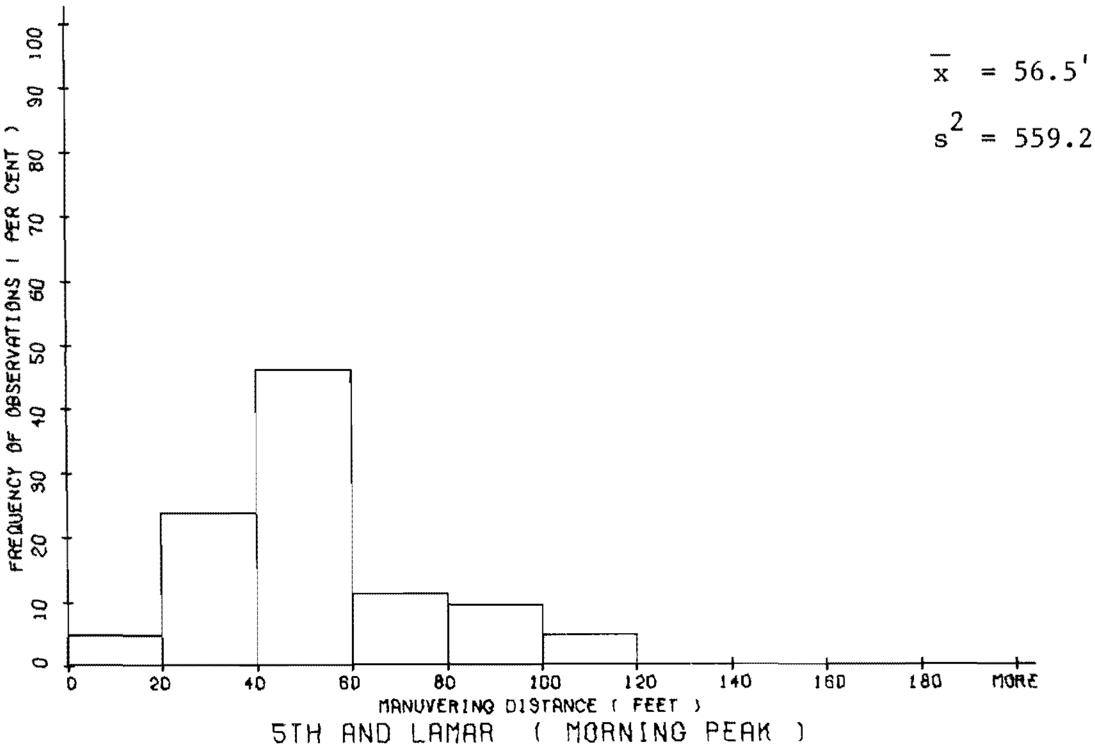


Fig C.8. Entrance distances at the 5th & Lamar and 6th & Lamar intersections during evening peak periods.



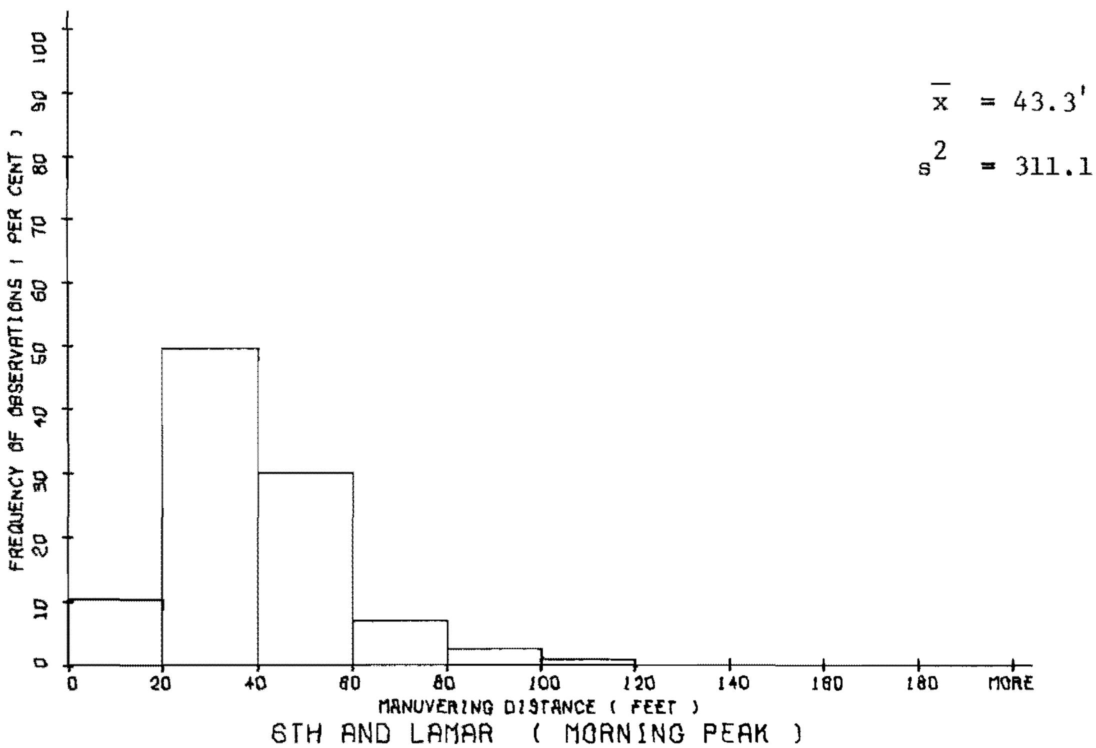
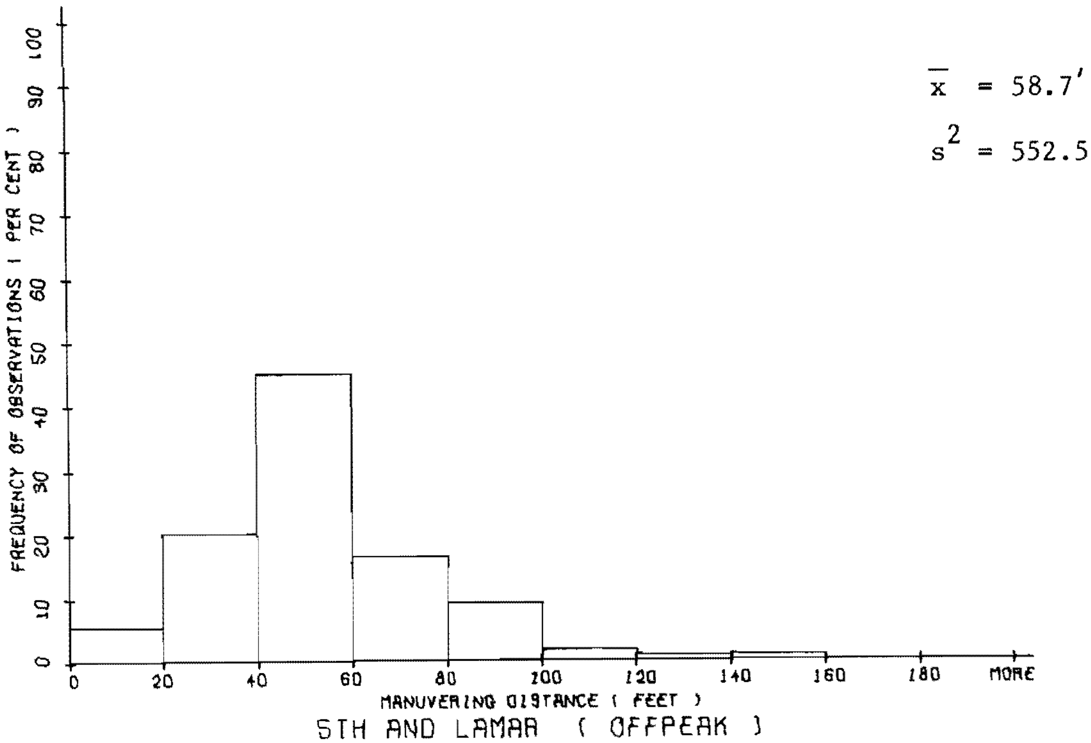


Fig C.9. Maneuvering distances at the 5th & Lamar and 6th & Lamar intersections during morning peak periods.



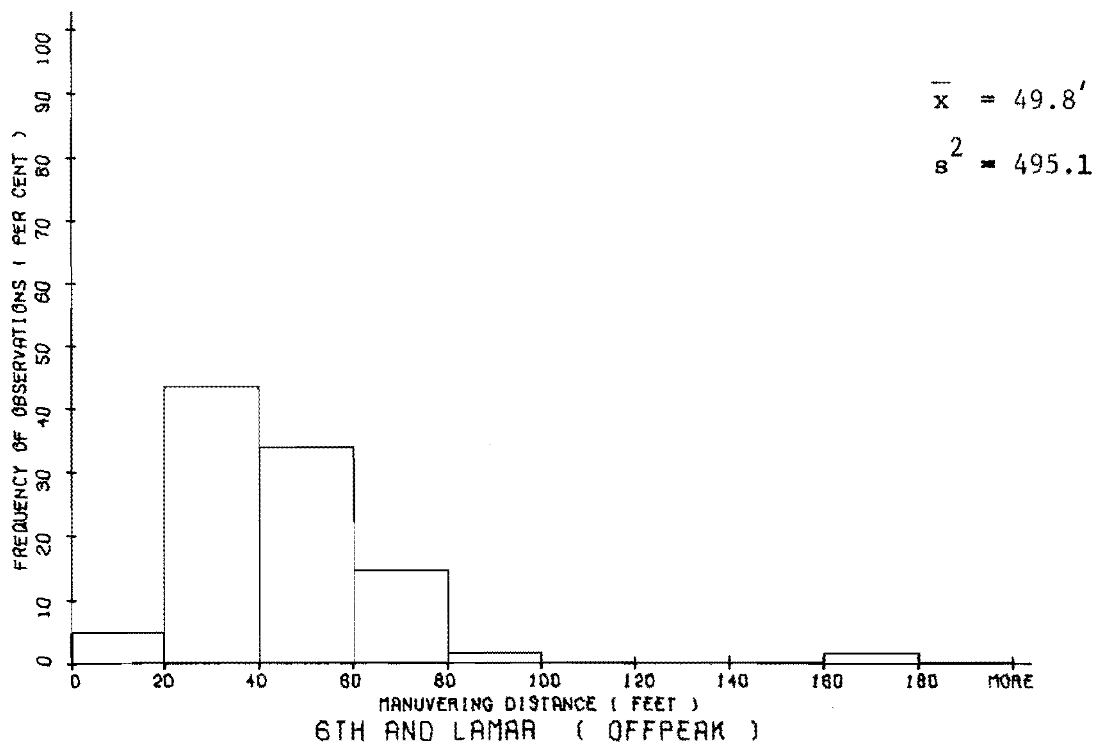
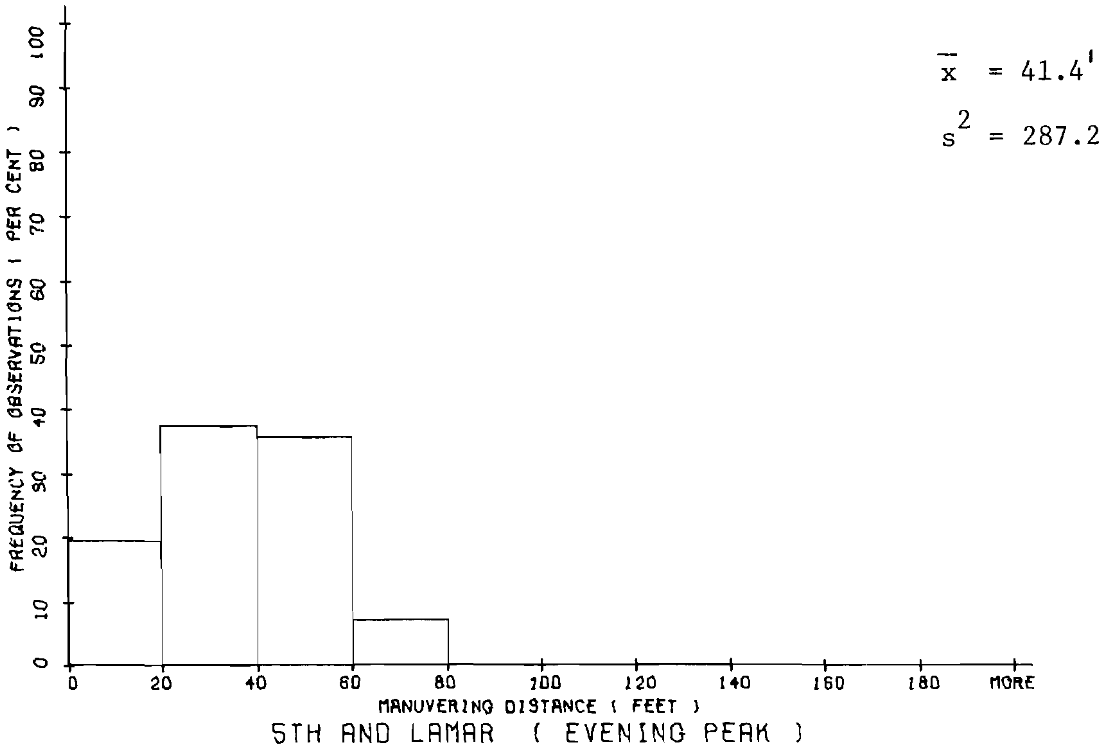


Fig C.10. Manuevering distances at the 5th & Lamar and 6th & Lamar intersections during offpeak periods.



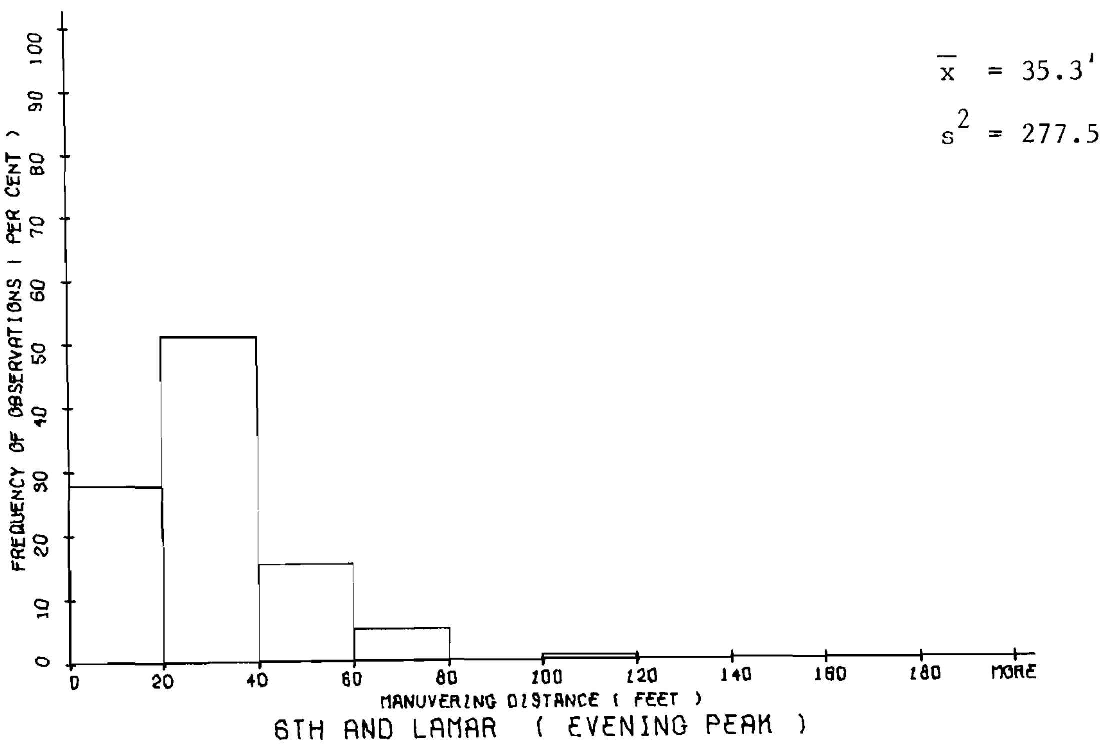


Fig C.11. Maneuvering distances at the 5th & Lamar and 6th & Lamar intersections during evening peak periods.

TABLE C.2. VOLUME DATA AT BURNET & ANDERSON

	Lanes 1&2	Intersection Left Turn	Lane 4	Lane 5
3:00	178	62	66	80
3:15	215	53	101	107
3:30	207	51	114	111
3:45	204	52	85	101
4:15	296	66	123	146
4:30	192	40	88	96
4:45	244	55	116	141
5:00	182	30	93	96
Total	1718	409	786	878
Rate	215	51	98	110

The posted speed limit is 40 mph and the markings are standard CTWLTML markings with 3-inch-diameter buttons on top of the painted line. Eight-inch-diameter buttons were installed on one side of the left-turn lane at the intersection approach. The width of the left-turn lane is 11 feet with through lane widths ranging from 11 feet 8 inches to 13 feet.

The land use at the intersection is automobile service stations, with two driveways for access on Burnet Road. On the left side of the street before the intersection approach is the Northcross Shopping Mall, which has two driveways for access, one approximately 460 feet from the intersection. Both driveways have right turn deceleration lanes (9 feet 6 inches wide and 200 feet long). On the opposite side of the street is a shopping center consisting of a bowling center, food market, shoe store, toy shop, furniture store, and other miscellaneous shops. The entire shopping center has five driveways, with the first one located approximately 300 feet from the intersection and the last one 800 feet from the intersection (Fig C.12).

Personal Observation. Since shopping centers are located on both sides of the street, a large amount of traffic is generated, especially on Saturday afternoon. At the intersection approach, there were several vehicles making left turns over the 8-inch circular buttons into the service station, which created occasional conflicts with the through lane traffic.

At the midblock location, various types of movement were made, as shown in Fig C.13. Almost 90 percent of the vehicles turning into the shopping center entered through driveway C and exited through driveway B. The probable cause is the "KEEP RIGHT" signs which are installed back to back between driveways B and C. Besides, very few vehicles used driveways E and F, especially F, which only one vehicle was observed using.

Thirty head-on conflicts were observed during the two-hour observation, but no accidents occurred. The following additonal observations were made at the site.

Situation A: When vehicle 1 is preparing to turn left into driveway D and there is a vehicle (vehicle 2) waiting in the CTWLTML and preparing to turn left into either driveway B or C, vehicle 1 will continue in the through lane until it passes vehicle 2 and then make a sharp

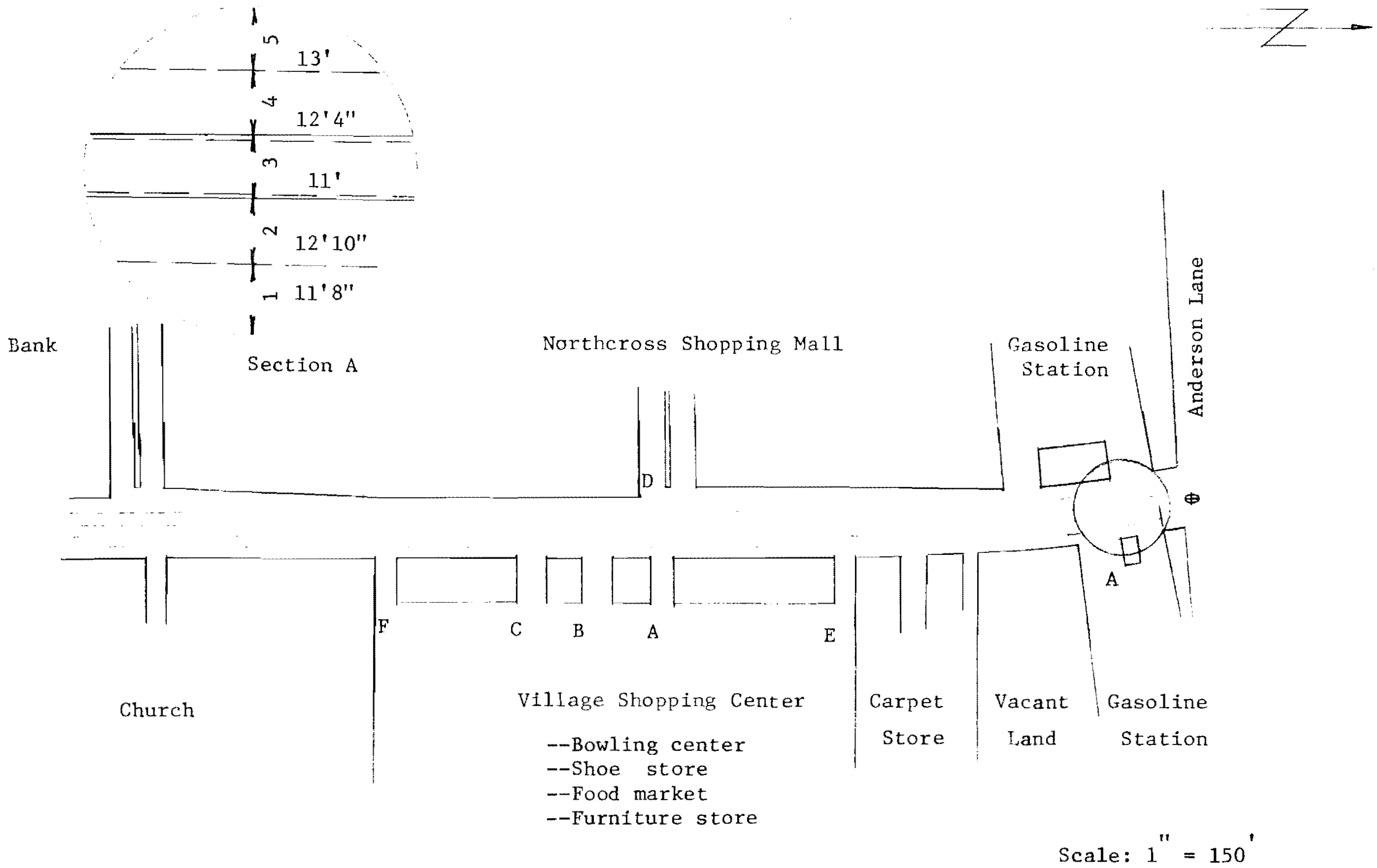


Fig C.12. Land use on Burnet south of Anderson.

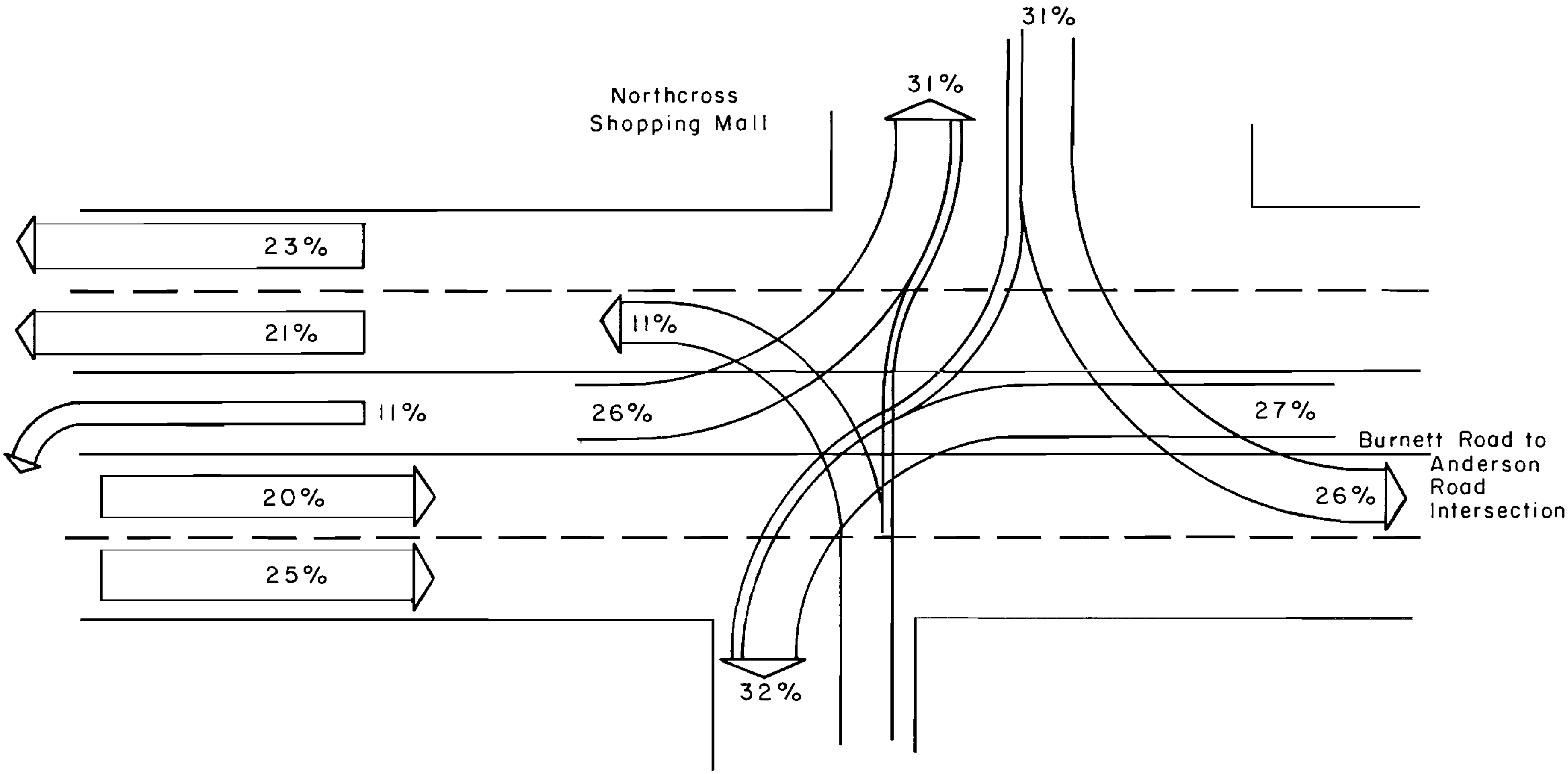


Fig C.13. Midblock movements on Burnet Road near Anderson Lane.

maneuver into the CTWLTML (Fig C.14). However, if there is a queue behind vehicle 2, no space is left for vehicle 1 to enter the CTWLTML, and vehicle 1 is forced to turn from the through lane. (One event with two vehicles turning from the through lane was observed during the two-hour observation.)

Situation B: Situation B is similar to situation A, but vehicle 1 and vehicle 2 are both in the CTWLTML. This time, vehicle 1 stops in the CTWLTML until vehicle 2 completes its left-turn movement and then proceeds to make its turning movement. When there is a queue behind vehicle 2 vehicle 1 stays in the CTWLTML until the queue is clear. There were no cases in which vehicle 1 left the CTWLTML with the exception of those in which it decided not to make the turning movement at this location (Fig C.15).

Situation C: When there is a vehicle (vehicle 1) waiting in the CTWLTML and preparing to enter driveway D, the opposing vehicle (vehicle 2) waits in the CTWLTML until vehicle 1 finishes its turning movement and then proceeds either to enter either driverway B or C or to enter through driveway A, which is seldom used by the motorists (Fig C.16).

Situation D: When vehicle 2 is preparing to enter any one of the three driveways into the shopping center, the driver changes his choice of driveways when he sees a vehicle waiting to turn left from that particular driveway into the main street. A possible controlling factor is the driveway width (which ranges from 21 feet to 31 feet) and the lateral position of the vehicle in the driveway (Fig C.17).

Situation E: A vehicle turning from a driveway into the main street seldom uses the CTWLTML as an acceleration lane unless there are vehicles approaching on the through lanes. A possible reason is that the driver tends to use a minimum effort to finish his maneuvering. In the case where all through lanes are vacant, it is easier to turn directly into the through lane to secure an acceptable gap.

Lateral Placement. Lateral placement of vehicles at the approach to Burnet & Anderson is illustrated in Fig C.18. The average displacement is 6.04 inches to the right of the centerline of the left-turn lane.

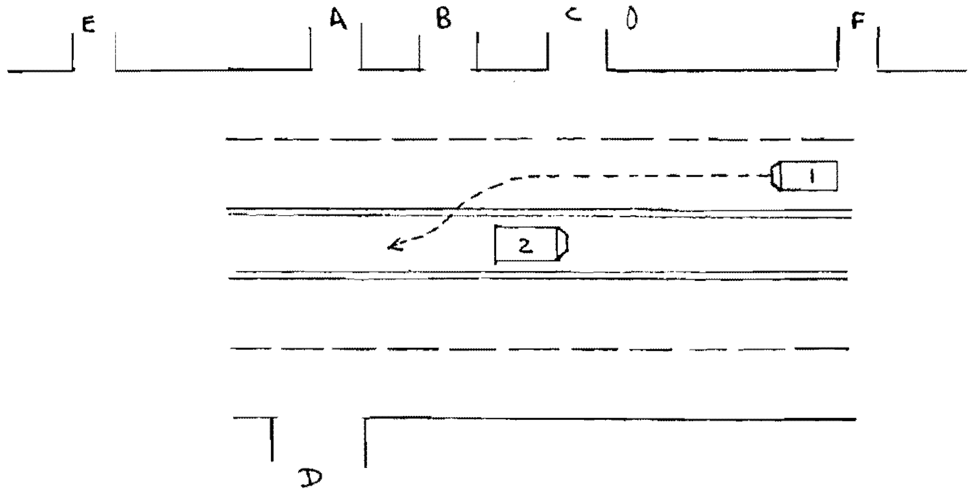


Fig C.14. Situation A.

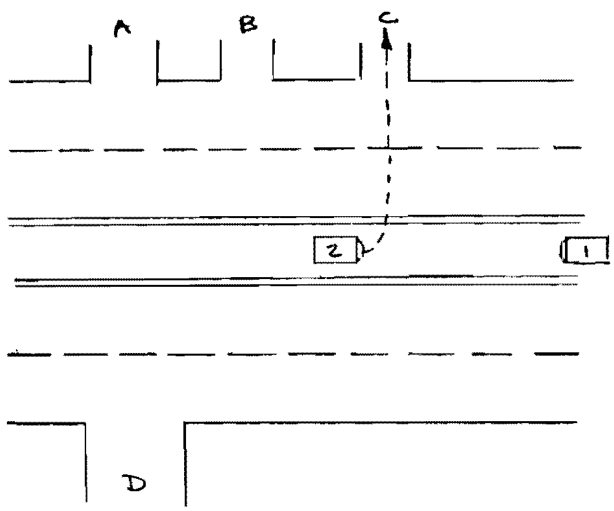


Fig C.15. Situation B.

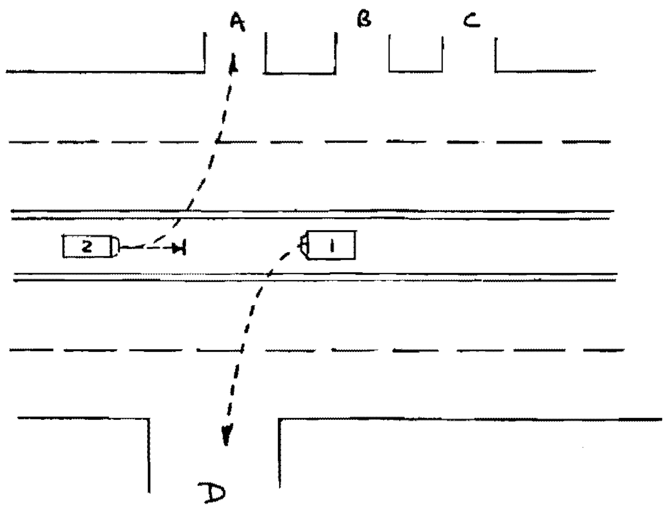


Fig C.16. Situation C.

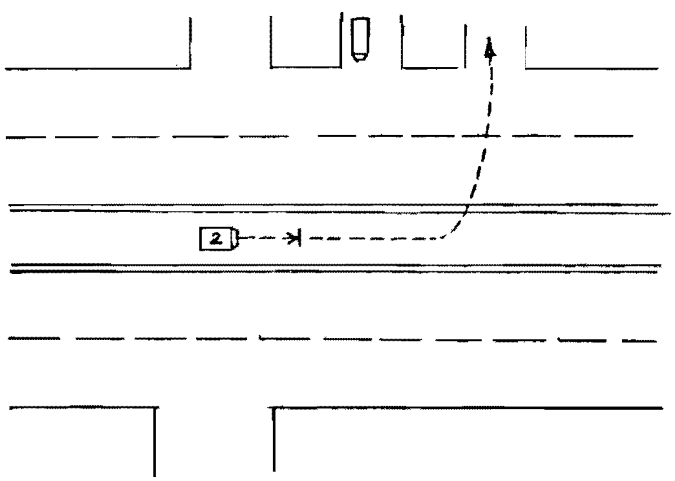


Fig C.17. Situation D.

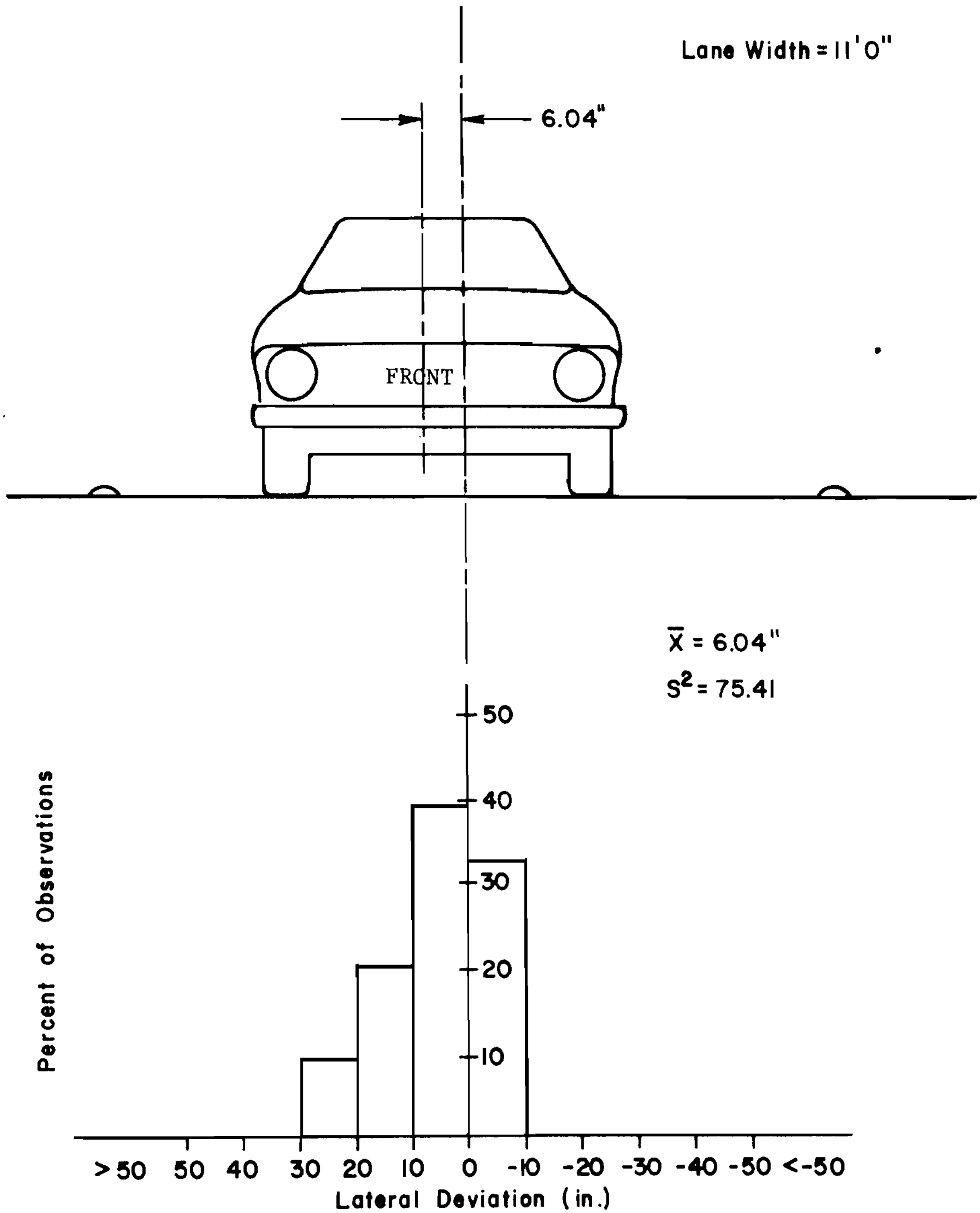


Fig C.18. Lateral deviations at Burnet Road & Anderson Lane.

Entrance Distance. Entrance distances during offpeak and peak periods at the intersection approach are shown in Fig C.19. The average entrance distance was 286.7 feet during the offpeak period and was 317.2 feet during the peak period. Another characteristic observed is the range of entrance distances, which varied from 50 feet to 450 feet during the offpeak period and from 50 feet to more than 450 feet during the peak period. This degree of dispersion as indicated by the variance showed the degree of freedom or inconsistency of the drivers entering the CTWLTML.

The entrance distances during the peak period at the midblock section of this approach are summarized in Fig C.20. The average entrance distance was 260.5 feet, 18 percent shorter than the entrance distance at the intersection approach. The range of entrance distances varied from 0 to more than 450 feet, and the degree of dispersion was 19561.1, 82 percent larger than the dispersion at the intersection.

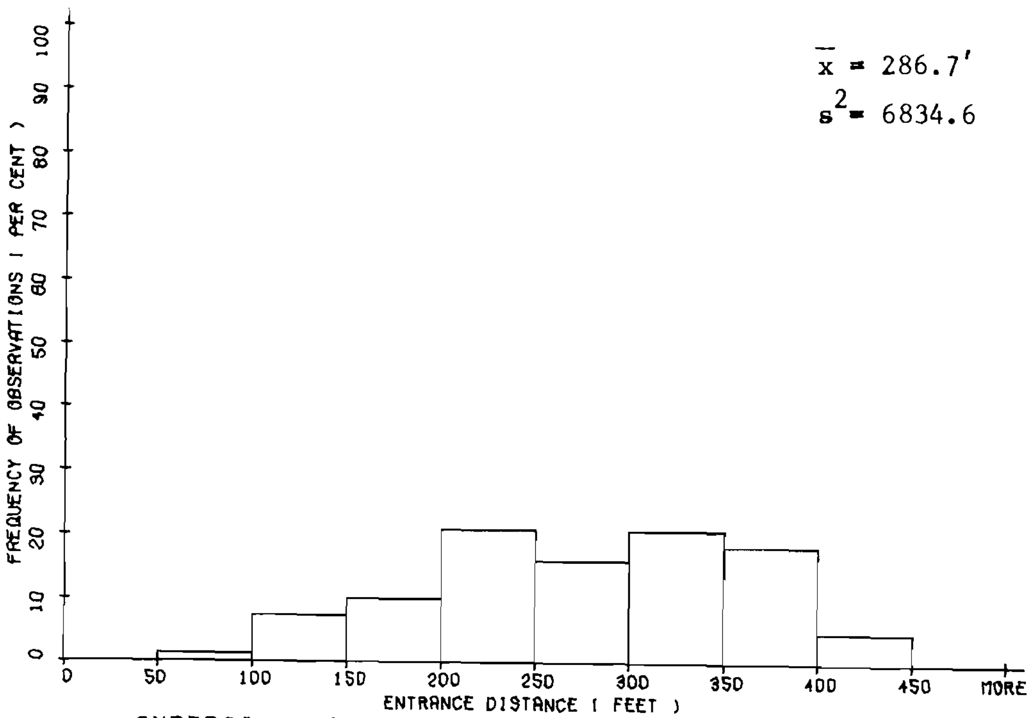
Maneuvering Distance. Maneuvering distances during the peak period at the intersection and at the midblock section are illustrated in Fig C.21. The average maneuvering distances are 66.8 feet and 55.6 feet, respectively. The degree of dispersion is relatively consistent at both approaches.

26th & Guadalupe (Austin)

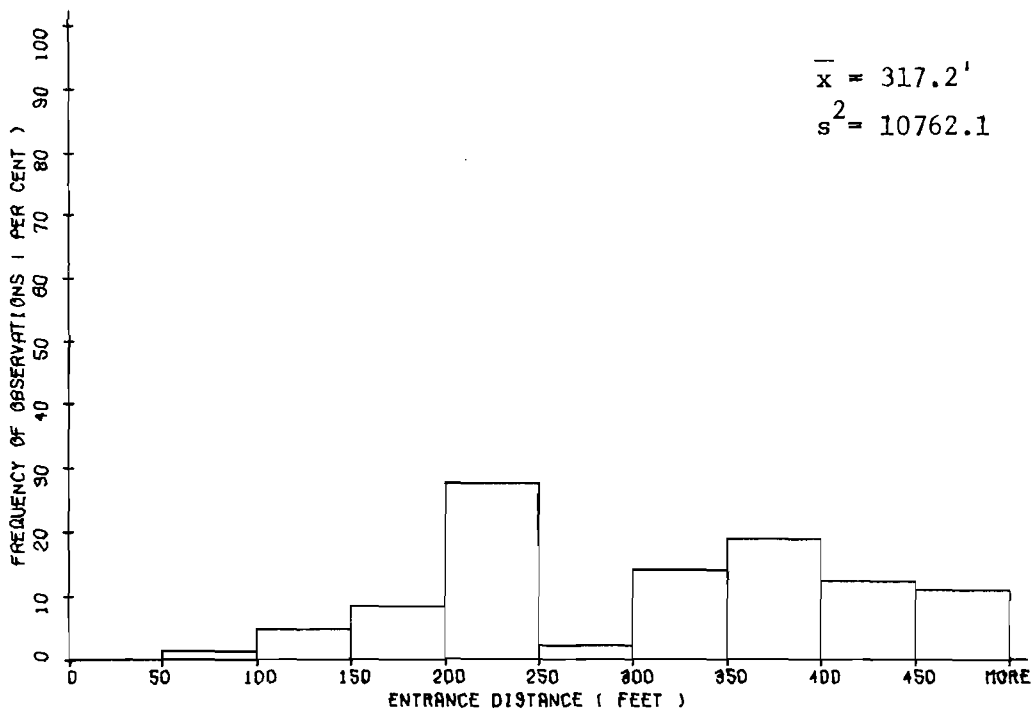
Site Characteristics. The site is located on Guadalupe Street between the offsets of 26th Street. North of 26th Street-W the facility is five lanes, with three lanes for southbound traffic and two lanes for northbound traffic. The average daily traffic at the site was 26,960 and the volume distribution during the study period is shown in Table C.3.

The posted speed limit is 35 mph, and the markings for the CTWLTML are standard markings with buttons. South of 26th Street-W typical markings divide three lanes on one side and two lanes on the other. However, there is no indication as to the proper use of the middle lane, as either a left-turn lane or an additional through lane.

26th Street-E and 26th Street-W are offset by approximately 200 feet. The width of the CTWLTML is 8 feet 11 inches, with through lane widths ranging from 10 to 12 feet. Both intersections are signalized and left turns are prohibited at the intersection at 26th Street-W. The land uses at the site are shops, restaurant and convenience stores, and the University (Fig C.22).



ANDERSON AND BURNET (OFFPEAK - INTERSECTION)



ANDERSON AND BURNET (PEAK - INTERSECTION)

Fig C.19. Entrance distances at the intersection approach of Burnet Road & Anderson Lane.

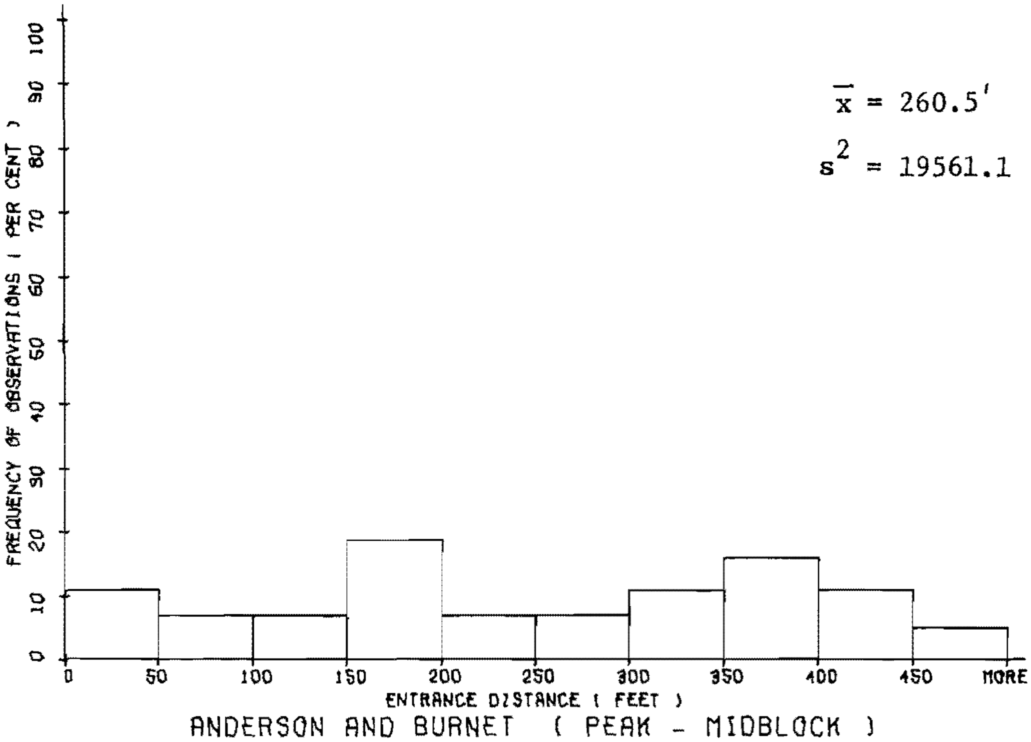
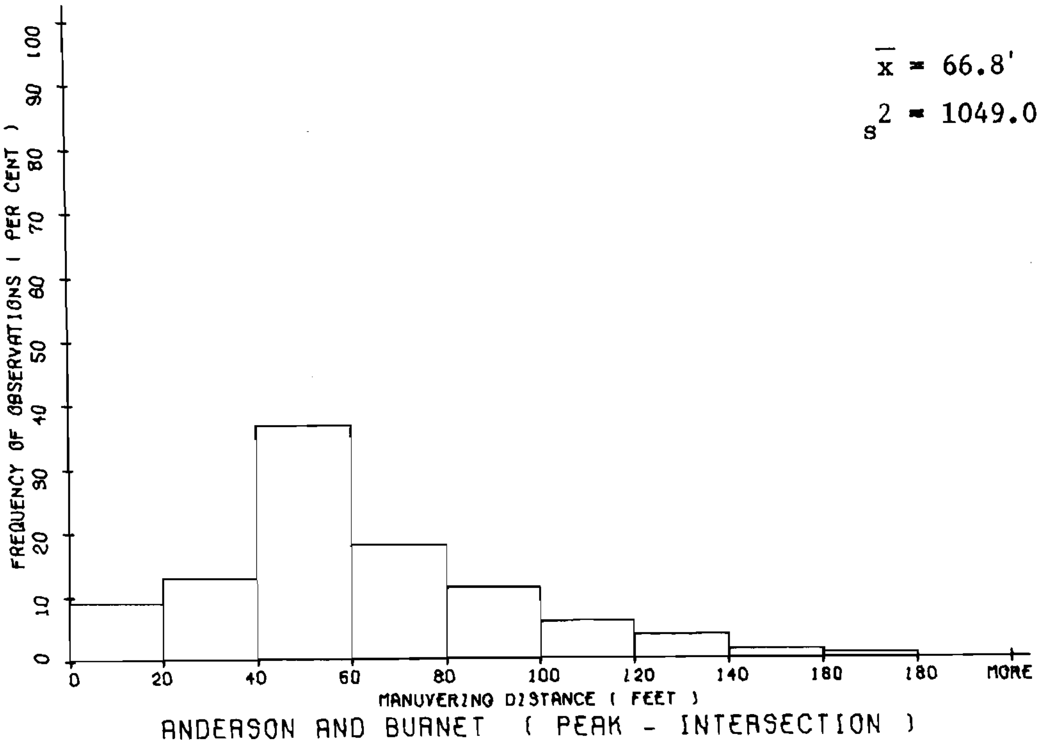


Fig C.20. Entrance distances at midblock of Burnet Road & Anderson Lane.



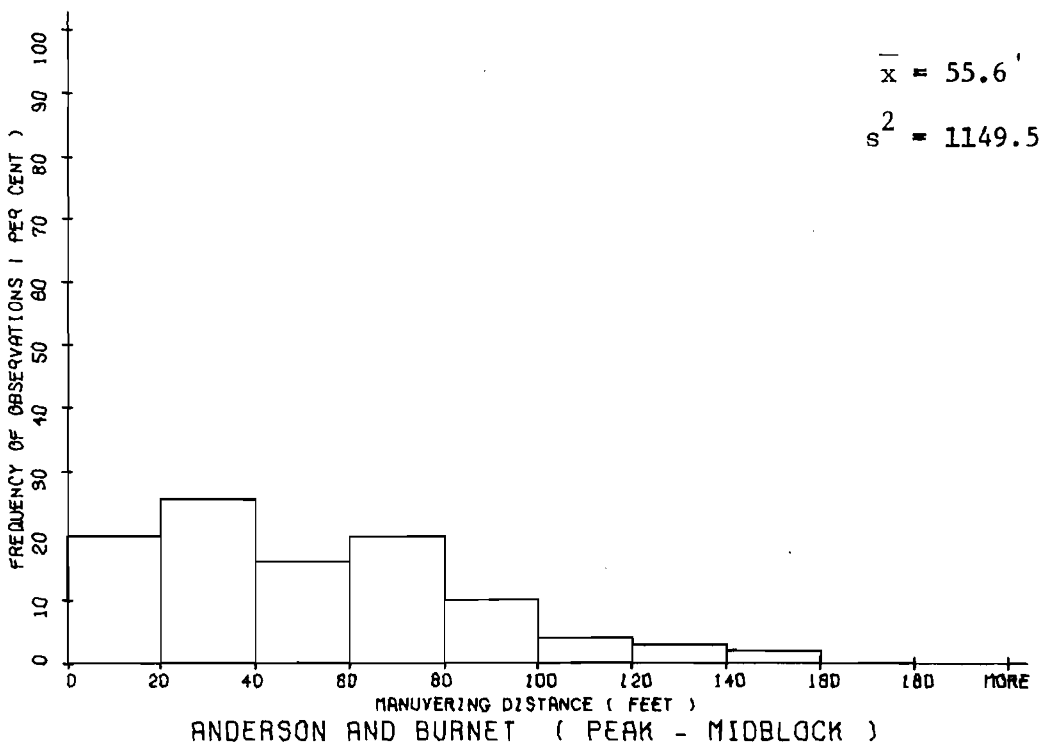


Fig C.21. Maneuvering distances at Burnet Road & Anderson Lane.

TABLE C.3. VOLUME DATA AT E. 26TH-GUADALUPE

	Lane 1 ↓	Lane 2 ↓	Intersection Left Turn	Lane 4 ↑	Lane 5 ↑
4:00	82	101	27	78	77
4:15	75	92	27	72	56
4:30	106	118	33	74	72
4:45	94	123	33	70	79
5:00	167	199	30	65	88
5:15	122	158	26	61	58
5:30	93	90	24	51	51
Total	741	881	200	471	481
Rate	106	126	29	67	69

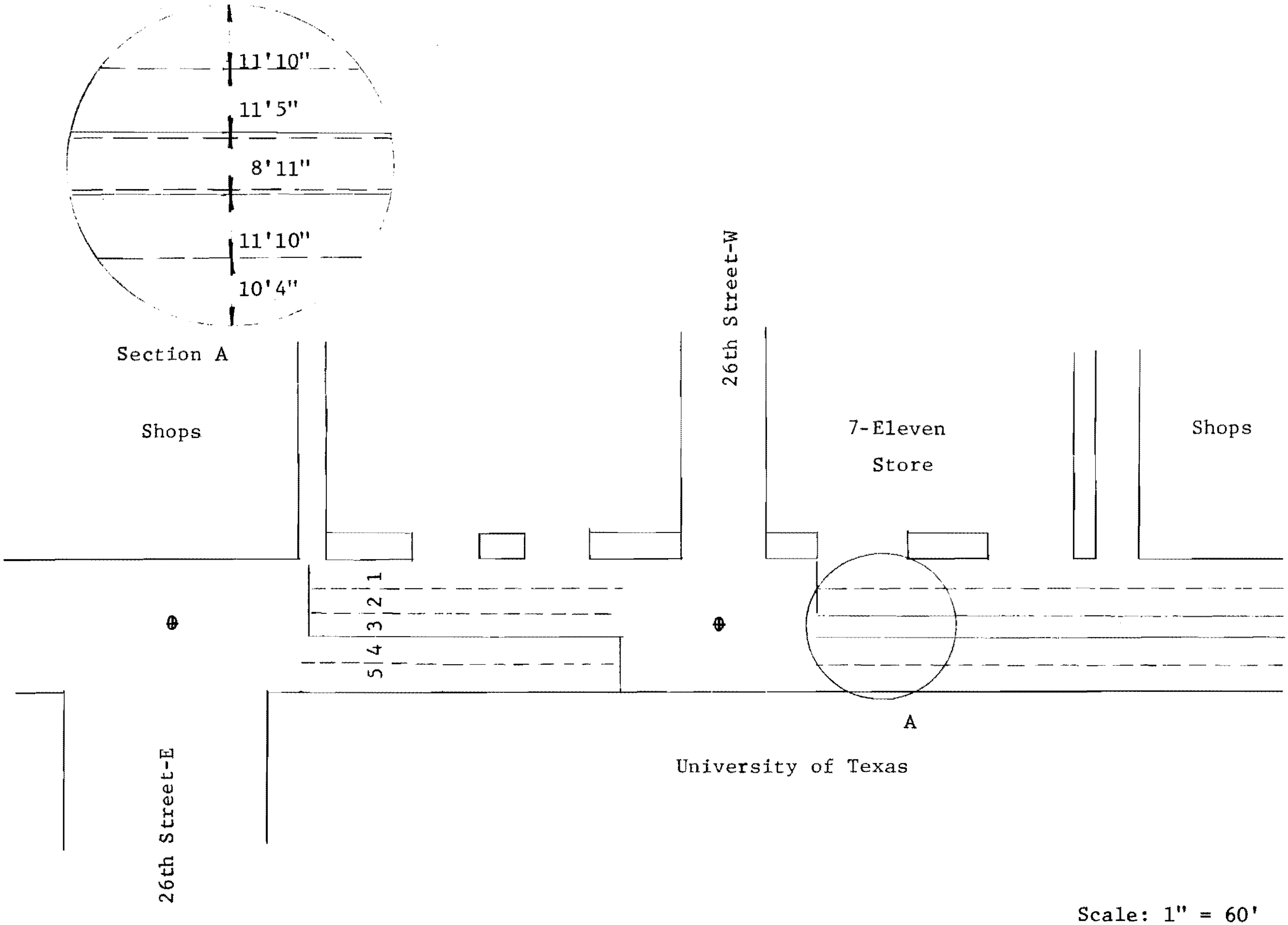


Fig C.22. Land uses on Guadalupe between the offset sections of 26th Street.

Personal Observation. During the one hour and forty-five minute observation at the site, there were 32 left turns into the restaurant from northbound traffic, and 10 out of these 32 left turns did not stop at the restaurant. They either egressed into 26th Street-W or made U-turns at the restaurant. There were also 27 left turns into the convenience food store, with 15 of them turning either into 26th Street-W or back onto Guadalupe Street without stopping at the store.

Since there are no clear indications on the use of the middle lane at the intersection of 26th Street-E, three vehicles turned left from the through lane (the one next to the middle lane) and a few southbound vehicles used the middle lane as a through lane. Since there is no left-turn lane for the northbound traffic, the majority of the 32 left turns indicated above made the turns from the through lane. However, a few of them used the middle lane as a left-turn lane.

Although a left-turn restriction sign is posted at the 26th Street-W intersection, seven vehicles were observed making left turns at the intersection during the study period. This type of maneuvering in conjunction with the left turns into the restaurant and convenience food store suggests a need for a left-turn lane. However, limitation of space restricts its provision.

A possible solution at the site is to leave it as it is with the exception of installing a raised barrier between 26th Street-E and 26th Street-W to restrict left turns into the restaurant. This restriction will force drivers to turn either at the intersection or at the convenience food store. The first case can be reduced by police enforcement, and the latter case should be encouraged since it fully utilizes the advantages of the CTWLTML on a one-side only left turn situation by eliminating the conflicts with the through lane vehicles from the same approach yet retaining storage space for the left-turn vehicles. However, some compromise should be reached between the convenience food store and the city to achieve its success.

Red River & 32nd Street (Austin)

Site Characteristics. The site is located on Red River Street north of 32nd Street. It is a three lane facility with the median lane used as a CTWLTML during the offpeak period and as an additional through lane for inbound and outbound traffic during the morning peak and evening peak periods, respectively. The average daily traffic was 12,240 and the volumes during the time of data collection are shown in Table C.4.

The speed limit is not posted along the street but is assumed to be 30 mph. The markings are standard reversible lane markings as recommended by MUTCD. The width of the median lane is 12 feet 4 inches with the through lane widths ranging from 11 feet 7 inches to 11 feet 11 inches. The land uses along the site are mostly residential with a small shopping center consisting of a grocery store, copy shop, laundry, and drug store. Three driveways are provided for ingress and egress from the shopping center, with only one on Red River Street (Fig C.23).

Personal Observation. The site is the only reversible lane facility in Austin. Its existence and regulation caused some confusion to some drivers. Along the section, some drivers made their left turns from the through lane; some drivers madeetheir left turns halfway in the through lane and halfway in the left-turn lane; and some drivers used it as a through or passing lane. These types of maneuvering are probably caused by unfamiliarity with the use of the lane.

At the intersection, where left turns from southbound traffic are prohibited during the evening peak period, eight drivers were observed making left turns from that approach between 4:00 and 4:30 p.m. These left turning vehicles caused hazards to the opposing traffic and the adjacent through lane traffic. In some cases, the opposing traffic had to stop for these left turners, and, in other cases, the left turners were forced to return to the through lane. One accident was observed when a left turning vehicle was forced to return to the adjacent through lane and collided with a vehicle in the adjacent through lane. It was only a minor collision and the two vehicles involved were driven away from the scene.

TABLE C.4. VOLUME DATA AT 32ND-RED RIVER

Time	Lane 1 ↓	Left Turn Volume	Lane 3 ↑
1:40	26	0	30
1:45	102	10	87
2:00	110	16	71
2:15	106	13	81
2:30	113	10	83
2:45	95	13	64
Total	552	62	416
Rate	104	12	78

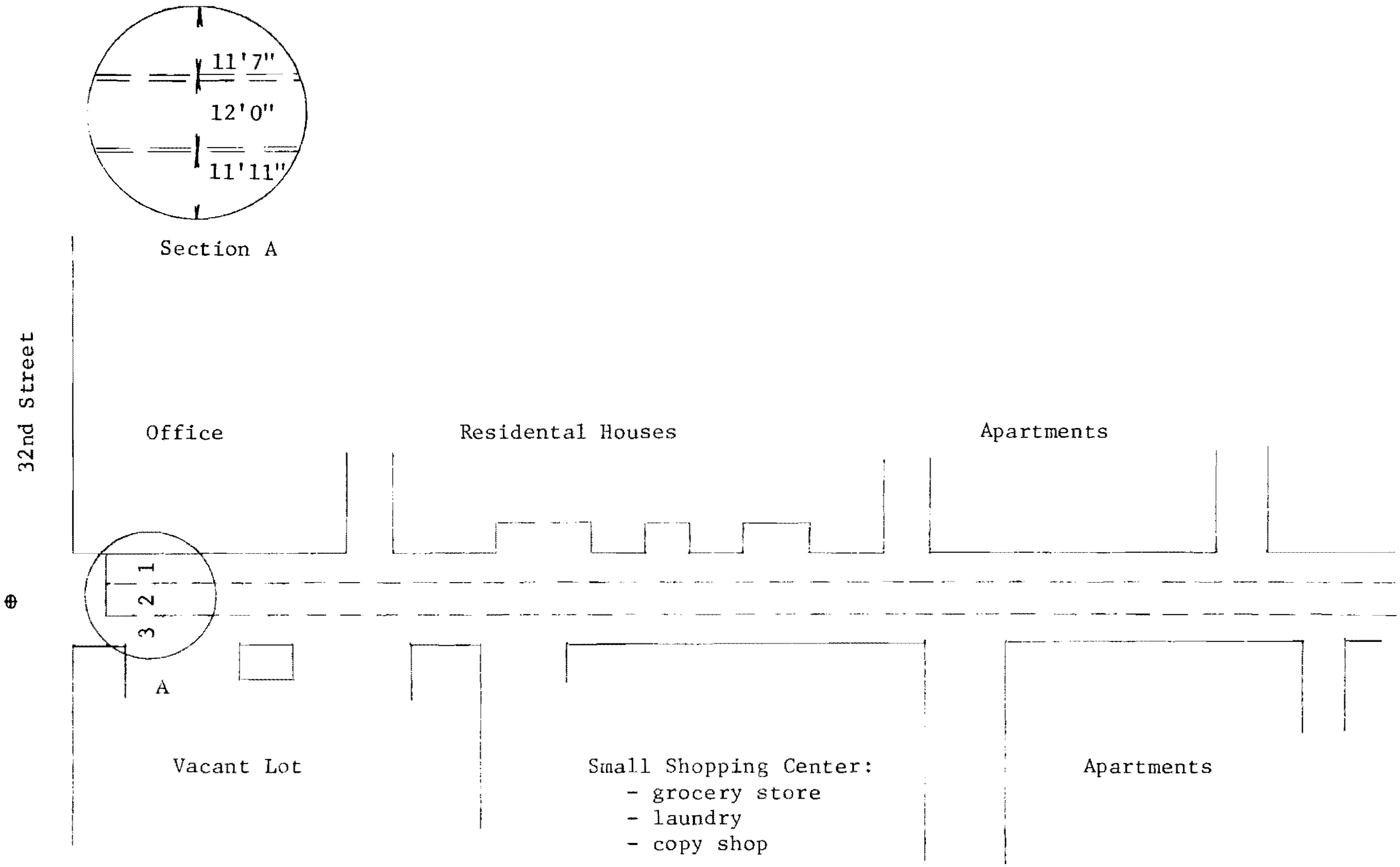


Fig C.23. Land uses on Red River north of 32nd.

Lateral Placement. Lateral placement of vehicles at the approach to 32nd & Red River is illustrated in Fig C.24. The average displacement was 12.92 inches to the right of the centerline of the left-turn lane.

Entrance Distance. The entrance distance during offpeak periods at this approach is illustrated in Fig C.25. The average entrance distance was 234.2 feet; the range was from 0 to more than 450 feet.

Maneuvering Distance. The maneuvering distance during offpeak periods at the approach is illustrated in Fig C.26. The average maneuvering distance was 86.2 feet; the range was from 0 to more than 180 feet.

Bigham & Camp Bowie (Fort Worth)

Site Characteristics. The site is located on Camp Bowie Boulevard, east of Bigham Street. It is a six-lane facility with raised COWLTML installed at the intersection approach. The average daily traffic at the site is 28,700. The posted speed limit is 35 mph, and 8-inch-diameter ceramic buttons on top of the painted line are used as markings on the opposite side of the raised island. The width of the left-turn lane is 8 feet 6 inches, and the adjacent land use is commercial shopping.

Lateral Placement. Lateral placement at this approach is illustrated in Fig C.27. The average displacement was 1.56 inches to the right of the centerline of the left-turn lane. The variance shown in the bar chart is relatively small compared to the other intersections. This might be caused by the width of the left-turn lane, which is only 8 feet 6 inches wide.

45th & Lamar - Northbound (Austin)

Site Characteristics. The site is located on Lamar Boulevard south of 45th Street. It is a five-lane facility with a continuous two-way left-turn lane at midblock and a raised COWLTML at the intersection approach. The average daily traffic at the site was 25,780 and the volumes during the time of data collection are shown in Table C.5.

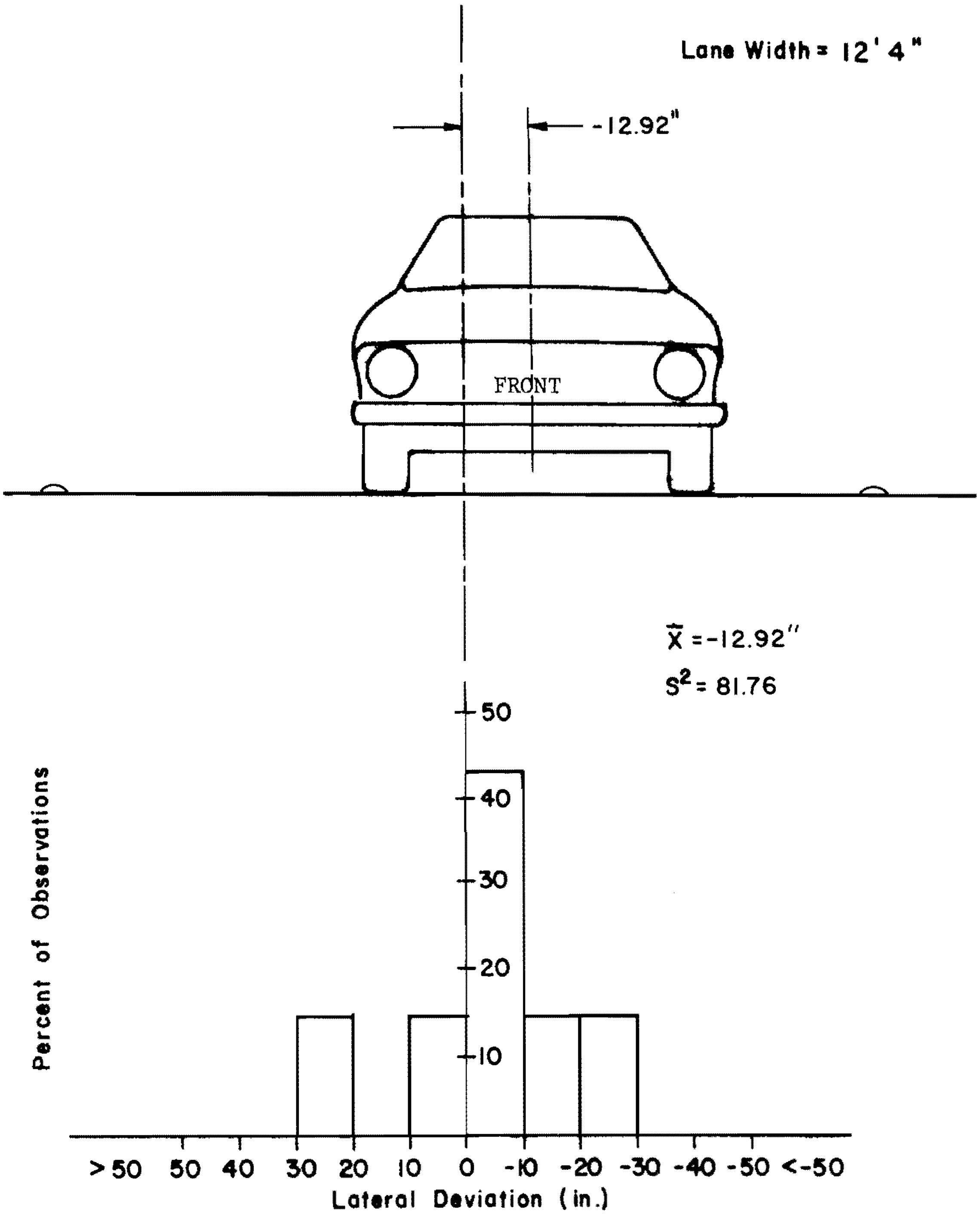


Fig C.24, Lateral placement at 32nd & Red River.

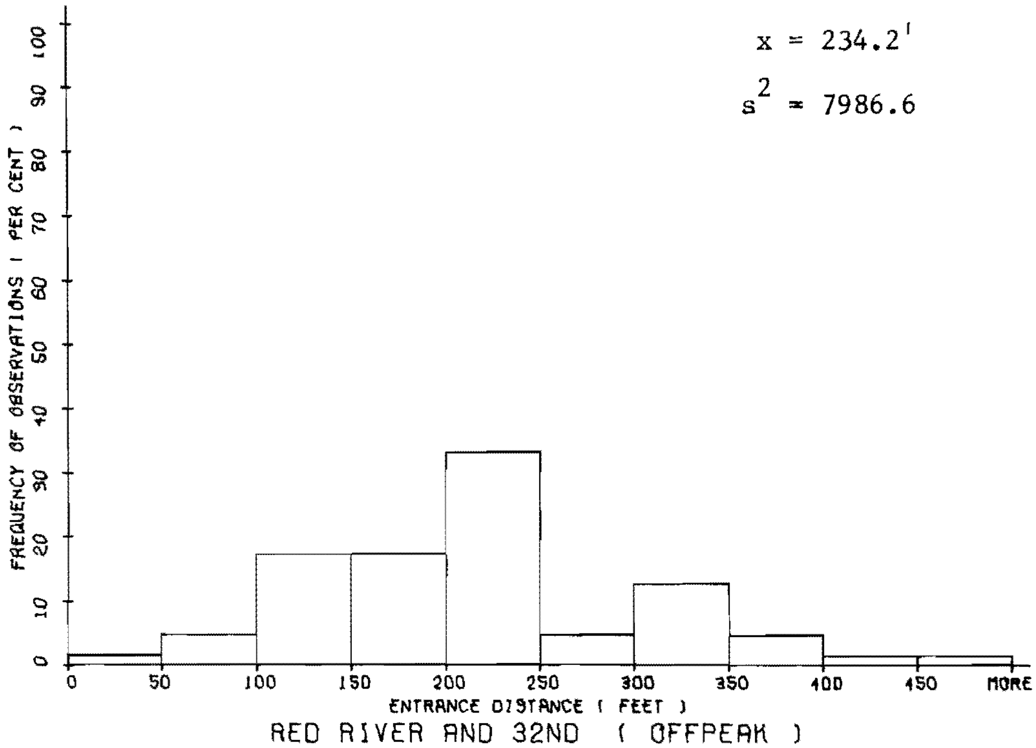


Fig C.25. Entrance distance at 32nd & Red River.

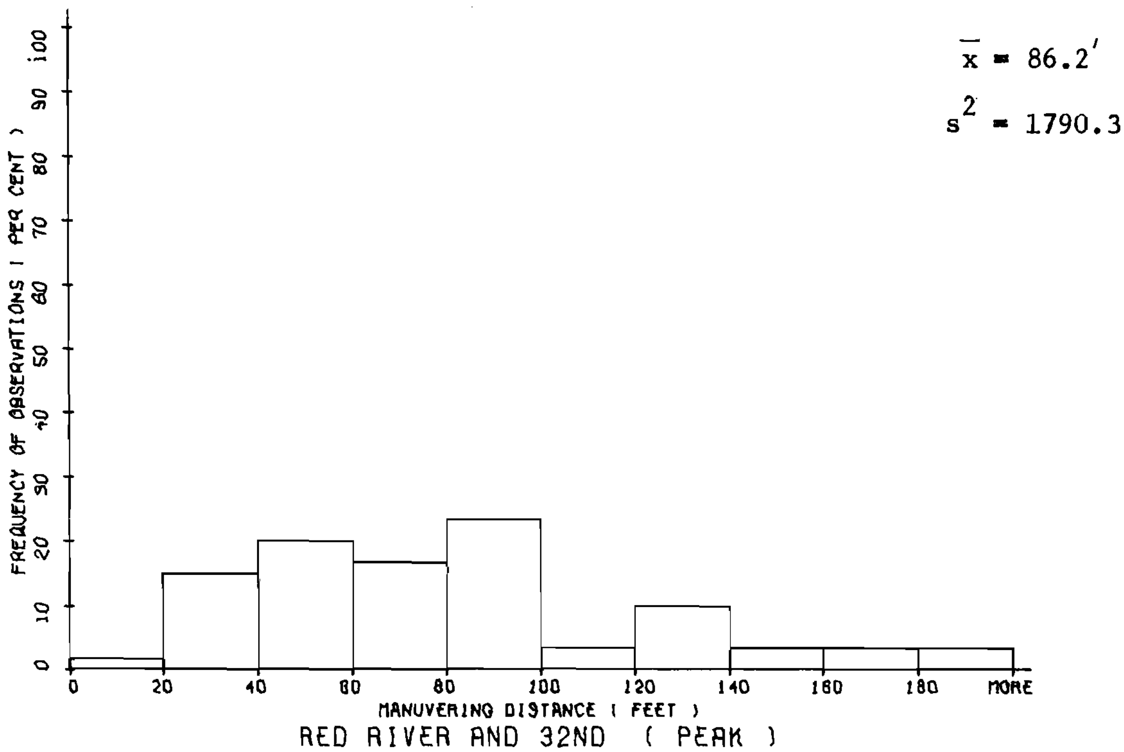


Fig C.26. Maneuvering distance at 32nd & Red River.

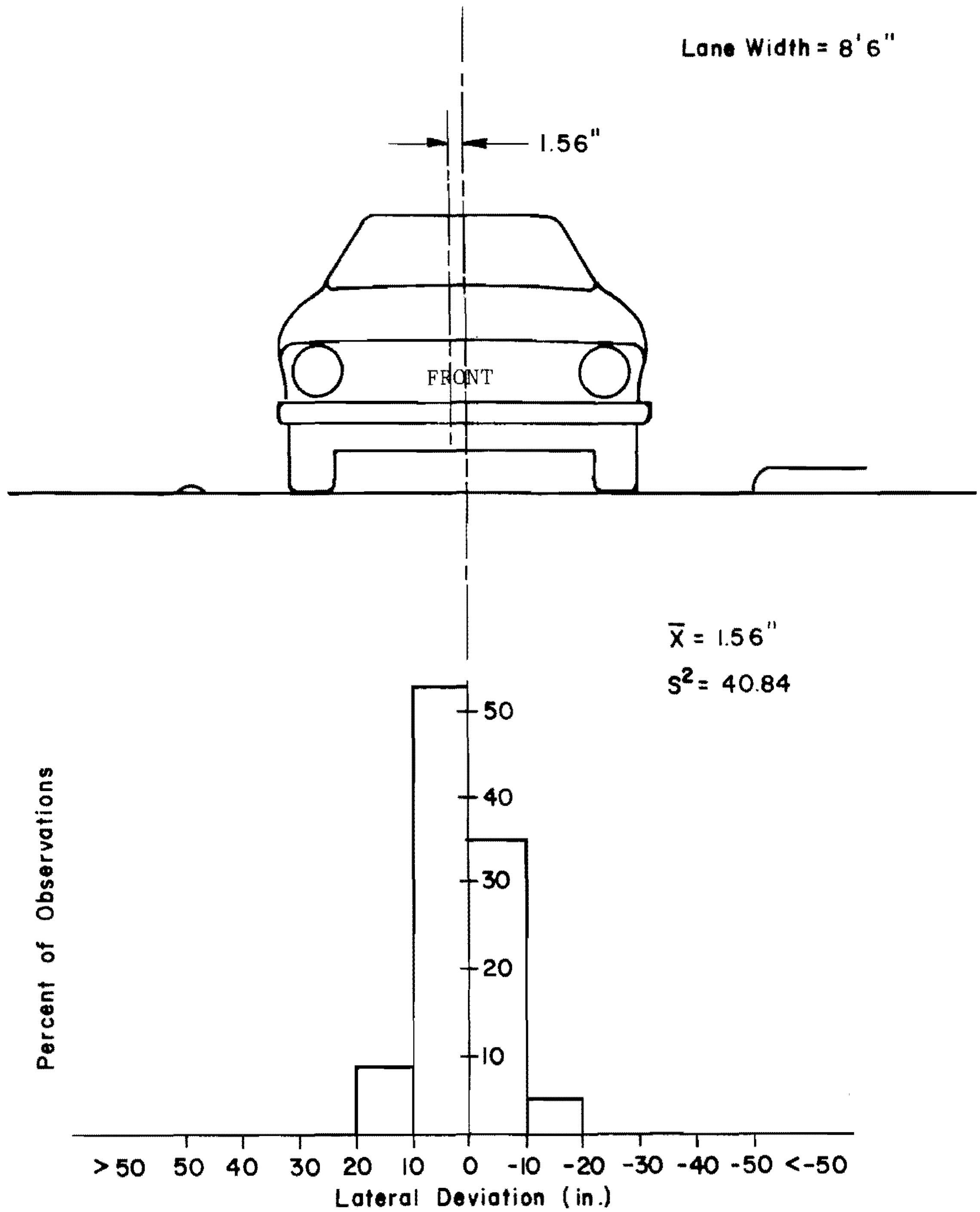


Fig C.27. Lateral placement at Bigham & Camp Bowie.

TABLE C.5. VOLUME DATA AT 45th STREET & LAMAR - NORTHBOUND

	Lanes* 1&2	Intersection Left Turns	Lane 4	Lane 5
2:00	160	42	93	80
2:15	142	48	85	80
2:30	139	47	74	71
2:45	158	46	91	62
Total	599	183	343	293
Rate	150	46	86	73
4:30	142	47	117	101
4:45	123	43	125	98
5:00	131	50	143	120
5:15	132	56	101	90
Total	417	196	486	409
Rate	104	49	122	102

* Opposing straight through volume on Lamar Blvd. only excluding right and left turns from 45th Street.

The posted speed limit at the site is 40 mph, with overhead signs indicating the purpose of the center line and its speed limit of 20 mph. Another overhead sign also provides advance warning of the end of the CTWLTML marking at midblock and changes to COWLTML marking at the approach, with a raised island on one side and white square buttons on top of the painted line on the other side of the left-turn lane. The storage length is approximately 170 feet and an opening of about 100 feet is provided for entry. The width of the left-turn lane is 13 feet with through-lane widths ranging from 10 feet 8 inches to 11 feet 5 inches.

The lane use on one side of the site is the Texas Department of Mental Health and Mental Retardation (MHMR), which has two driveways for access. The opposite side consists of various types of shops with no access to Lamar Blvd. except from the frontage road, where access is provided at the beginning and end of the block (Fig C.28).

Personal Observation

No conflicts were observed during the study periods since there were no left turning movements into the MHMR facility and all turning movements into the shops were handled by the frontage road. For this reason, the CTWLTML was used almost entirely for intersection left turns; on only two occasions was the lane used by southbound traffic for U-turn maneuvering.

Lateral Placement

Lateral placement of vehicles at the approach to 45th Street is illustrated in Fig C.29. This average displacement was .42 inch to the left of the centerline of the left-turn lane.

Entrance Distance

The entrance distances during offpeak and evening peak periods are shown in Fig C.30. The average entrance distance was 365.2 feet during the offpeak period and 332.0 feet during the evening peak period. The graph

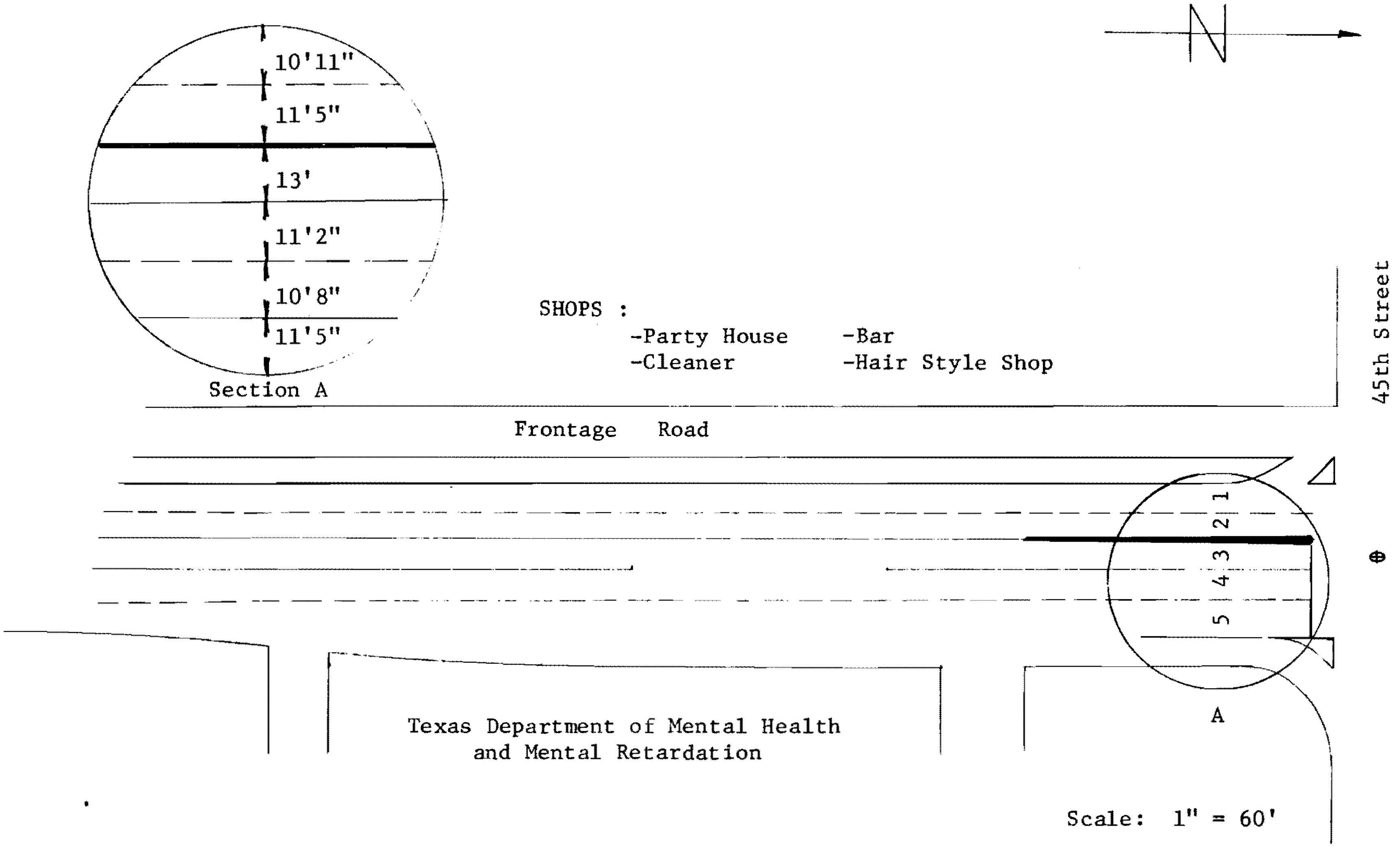


Fig C.28. Land use on Lamar south of 45th - Austin, Texas.

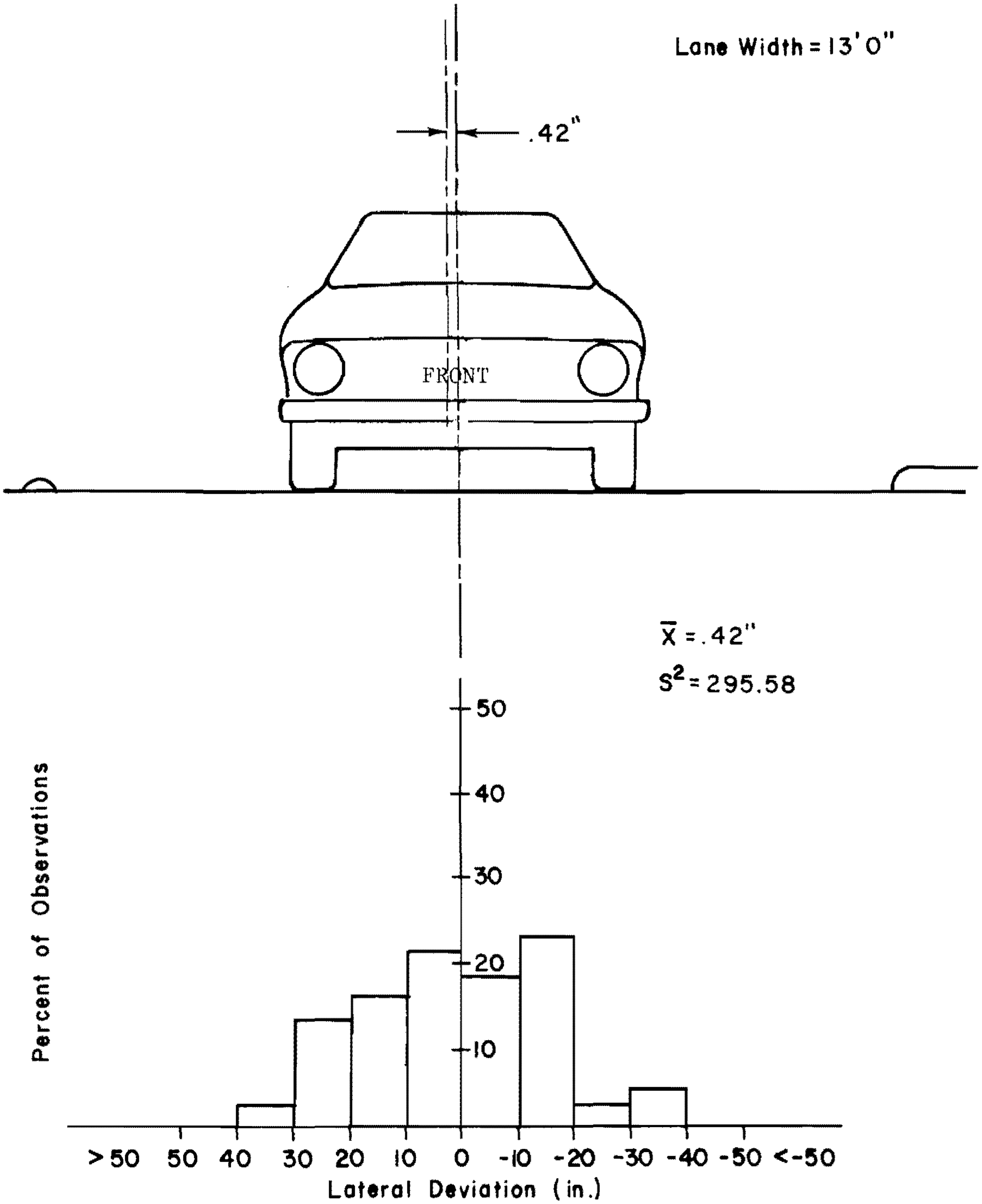
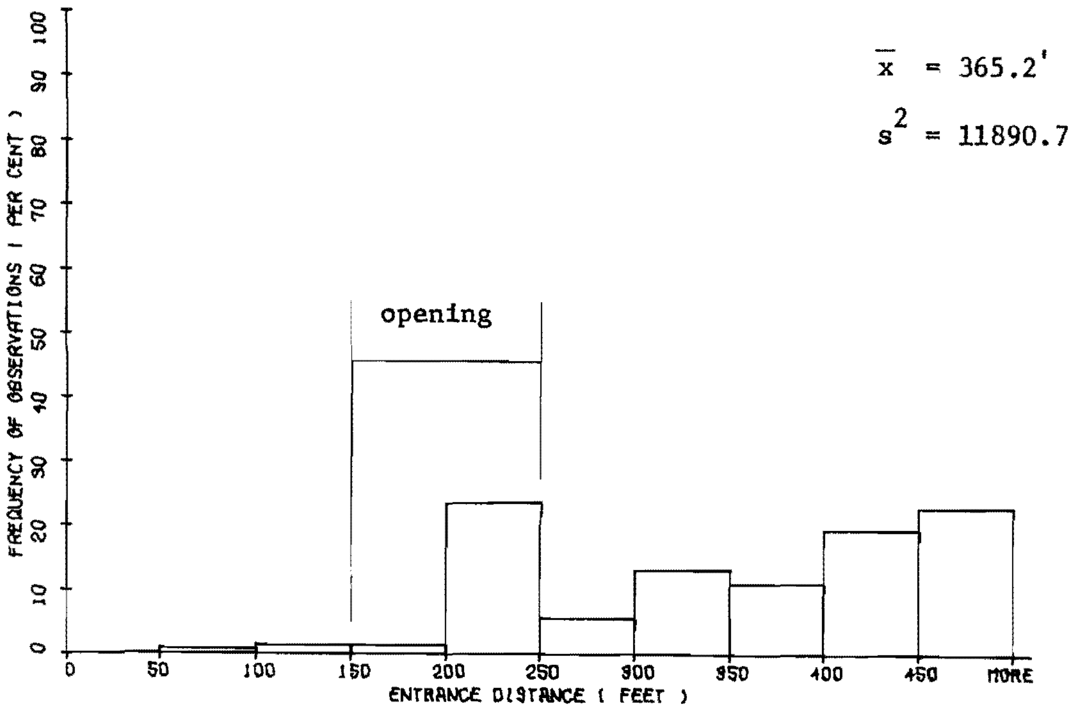


Fig C.29. Lateral deviations at 45th & Lamar (northbound).



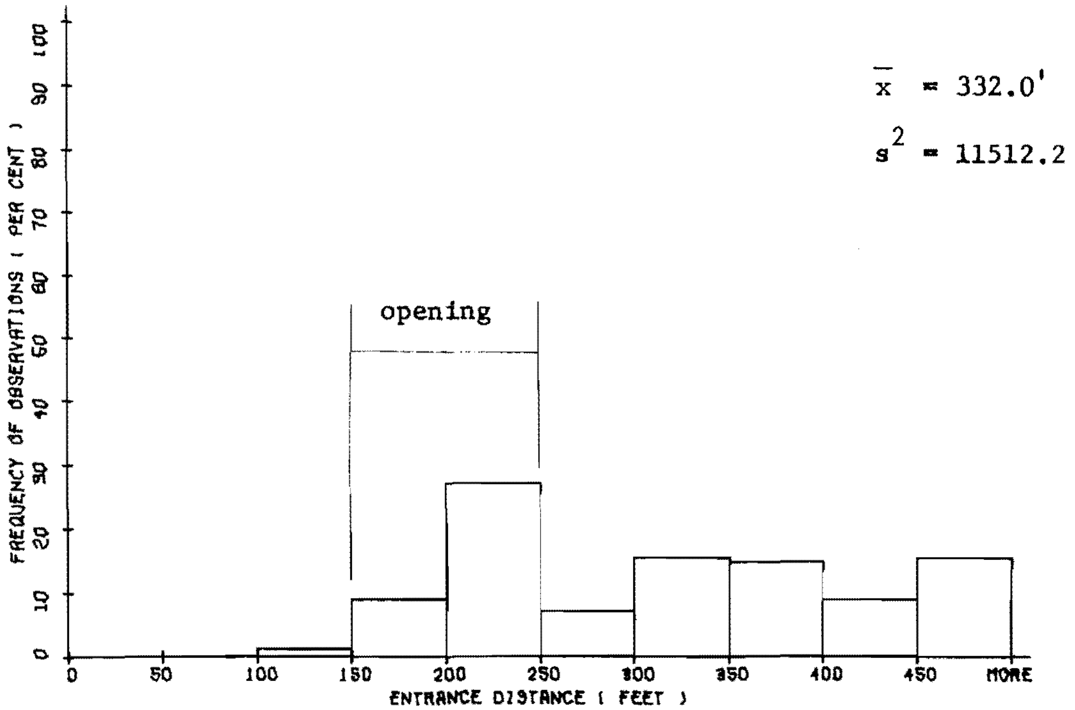


Fig C.30. Entrance distance at 45th & Lamar (northbound).

also illustrates that many motorists entered the CTWLTML from distances more than 450 feet from the intersection and neglected the opening provided for left-turn entry.

Maneuvering Distance

The maneuvering distances during offpeak and evening peak periods are shown in Fig C.31. The average maneuvering distances were 68.8 feet and 61.4 feet, respectively.

45TH AND GUADALUPE -- NORTHBOUND (Austin)

Site Characteristics

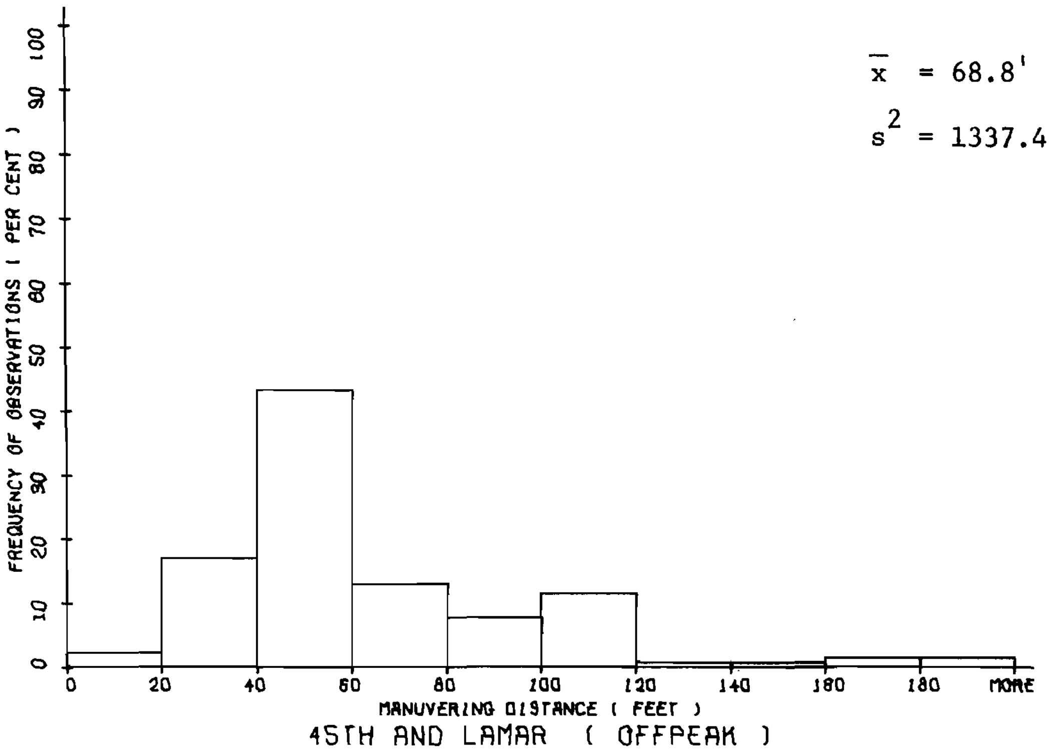
The site is located on Guadalupe Street south of 45th Street. It is a five-lane facility with a continuous two-way median left-turn lane at midblock and a flush COWLTML at the intersection approach. The average daily traffic is 23,210 and the volumes during the time of data collection are shown in Table C.6.

The posted speed limit is 35 mph, and the markings are standard CTWLTML markings at midblock and a flush COWLTML marking at the intersection approach, with square buttons on both sides of the lane. The storage length is approximately 170 feet and an opening of about 100 feet is provided for entry. The width of the left-turn lane is 11 feet 5 inches with through lane widths ranging from 11 feet 10 inches to 12 feet 10 inches.

The land use on one side of the site is the MHMR facility, and there is no access for left turn for northbound traffic. On the opposite side of the facility small retail stores are scattered along the site (Fig C.32).

Personal Observation

The site is restricted to one-way left turns only, and the stores along the opposite side generate very little left-turn traffic, with the exception of the convenience food store at the intersection. There were 31 left turns into and out of the store during the three-hour study period and they caused some conflicts with the through lane traffic; however, no accidents were observed.



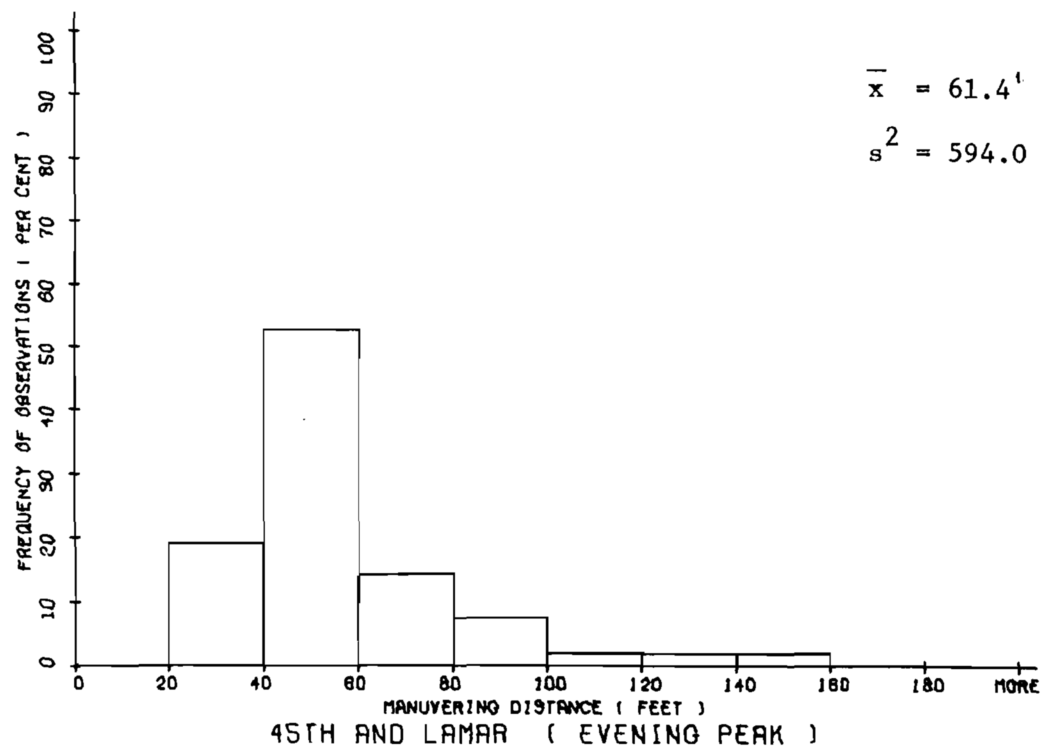


Fig C.31. Maneuvering distance at 45th & Lamar (northbound).

TABLE C.6. VOLUME DATA AT 45TH STREET & GUADALUPE (NORTHBOUND)

	Lanes* 1&2	Intersection Left Turn	Lane 4	Lane 5
3:15	109	35	83	100
3:30	105	31	80	103
4:00	121	40	80	118
4:15	122	42	81	120
4:30	111	52	94	135
5:00	77	76	167	174
5:15	98	87	184	174
5:30	98	40	135	155
Total	841	403	904	1079
Rate	105	50	113	135

* Opposing straight through volume on Guadalupe only, excluding right and left turns from 45th Street.

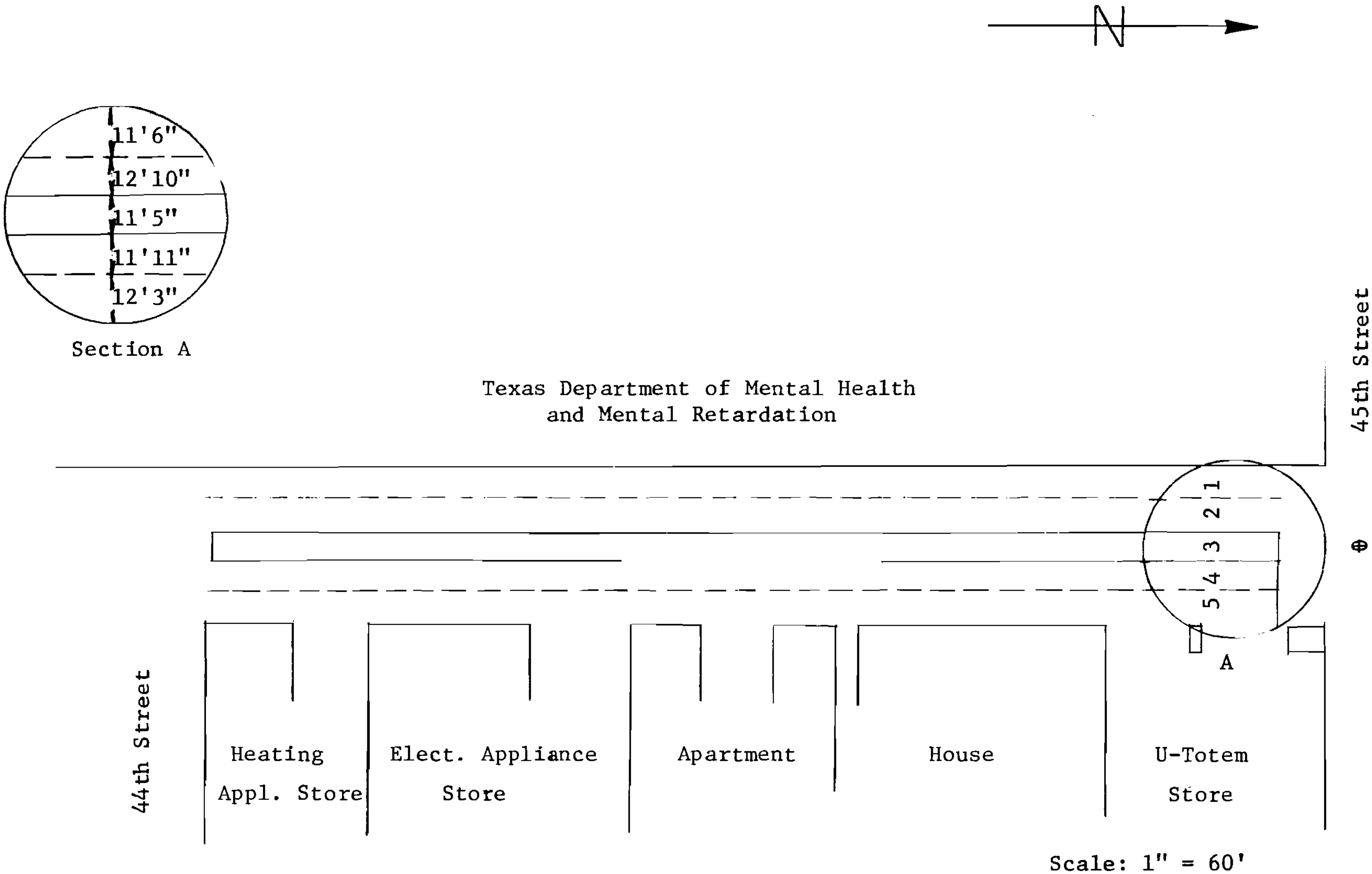


Figure C.32. Land use on Guadalupe, south of 45th.

Lateral Placement

Lateral placement of vehicles at the approach to 45th Street is illustrated in Fig C.33. The average displacement is 5.27 inches to the right of the center line of the left-turn lane.

Entrance Distance

The entrance distance during the evening peak period is shown in Fig C.34. The average entrance distance was 292.1 feet. Contrary to use at the site at 45th & Lamar northbound) more people used the opening provided for left-turn-lane entry.

Maneuvering Distance

The maneuvering distance during the evening peak period is shown in Fig C.35. The average maneuvering distance was 63.9 feet.

DENSON AND AIRPORT (Austin)

Site Characteristics

The site is located on Airport Boulevard west of Denson Street. It is a five-lane facility with a CTWLTML in the center. The average daily traffic at the site is 19,060.

The posted speed limit is 45 mph; the markings are standard CTWLTML marking with buttons. The width of the left turn lane is 11'10" and the land use at the site is a shopping center on one side and industrial areas behind the railroad track on the opposite side of the shopping center.

Lateral Placement

Only lateral placement was collected since there is a horizontal curve before the intersection that might influence the entrance distance and maneuvering distances. The lateral placement is illustrated in Fig C.36. The average displacement is 6.42 inches to the left of the center line of the left turn lane.

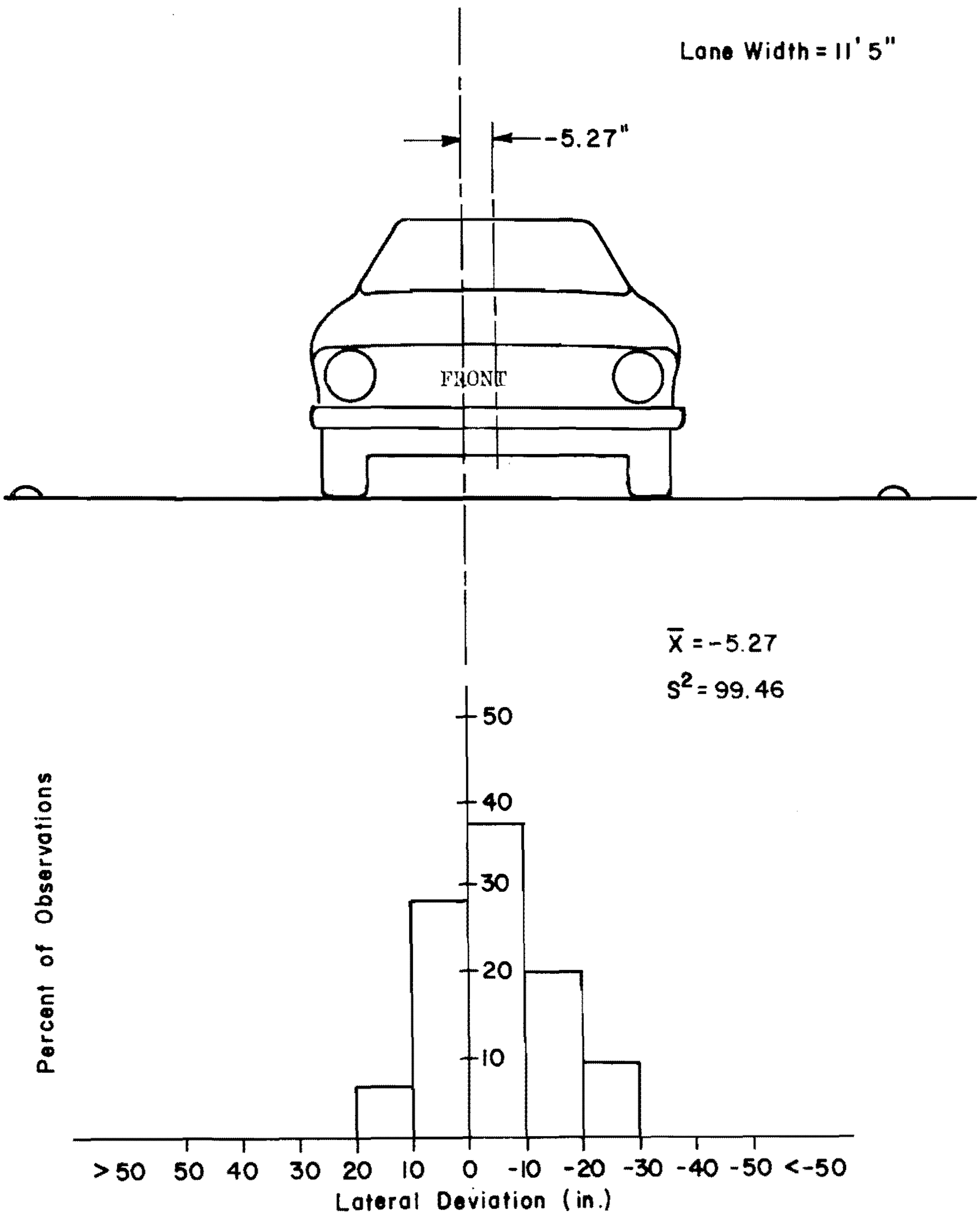


Fig C.33. Lateral deviations at 45th & Guadalupe (northbound).

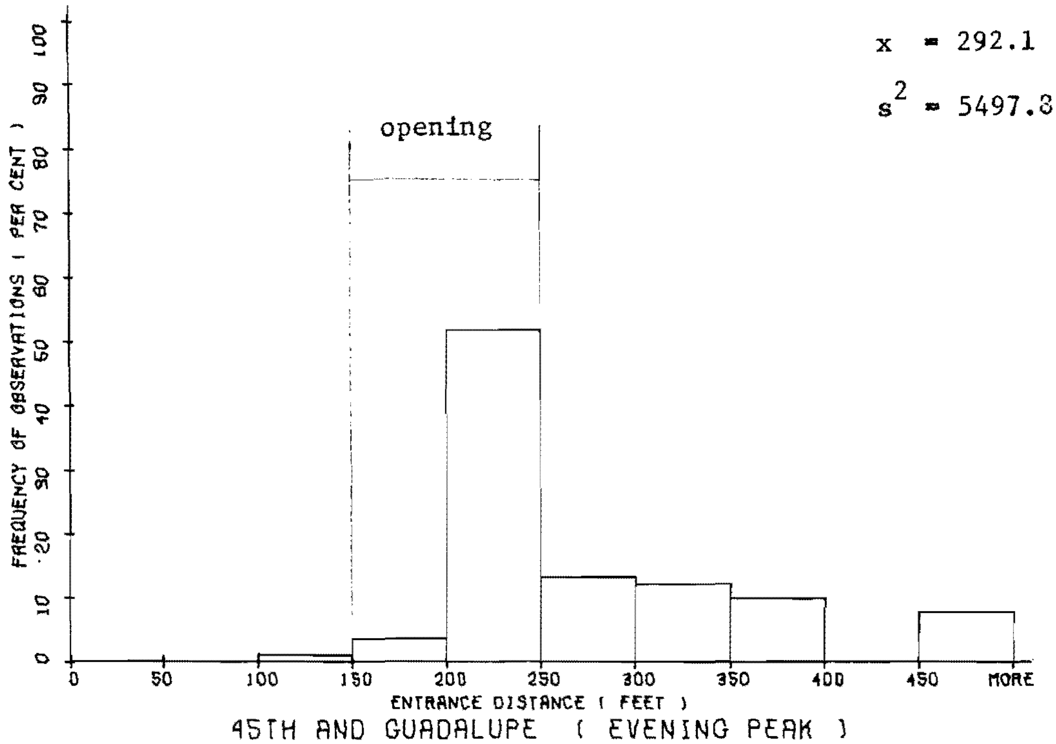


Fig C.34. Entrance distance at 45th & Guadalupe (northbound).

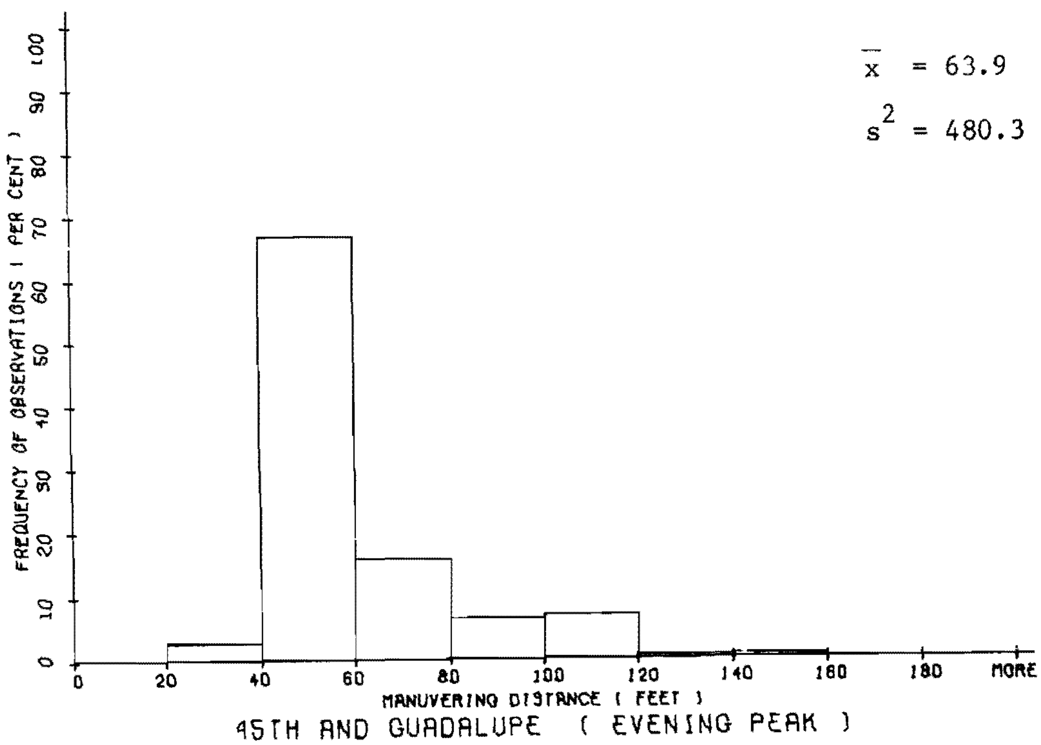


Fig C.35. Maneuvering distance at 45th & Guadalupe (northbound).

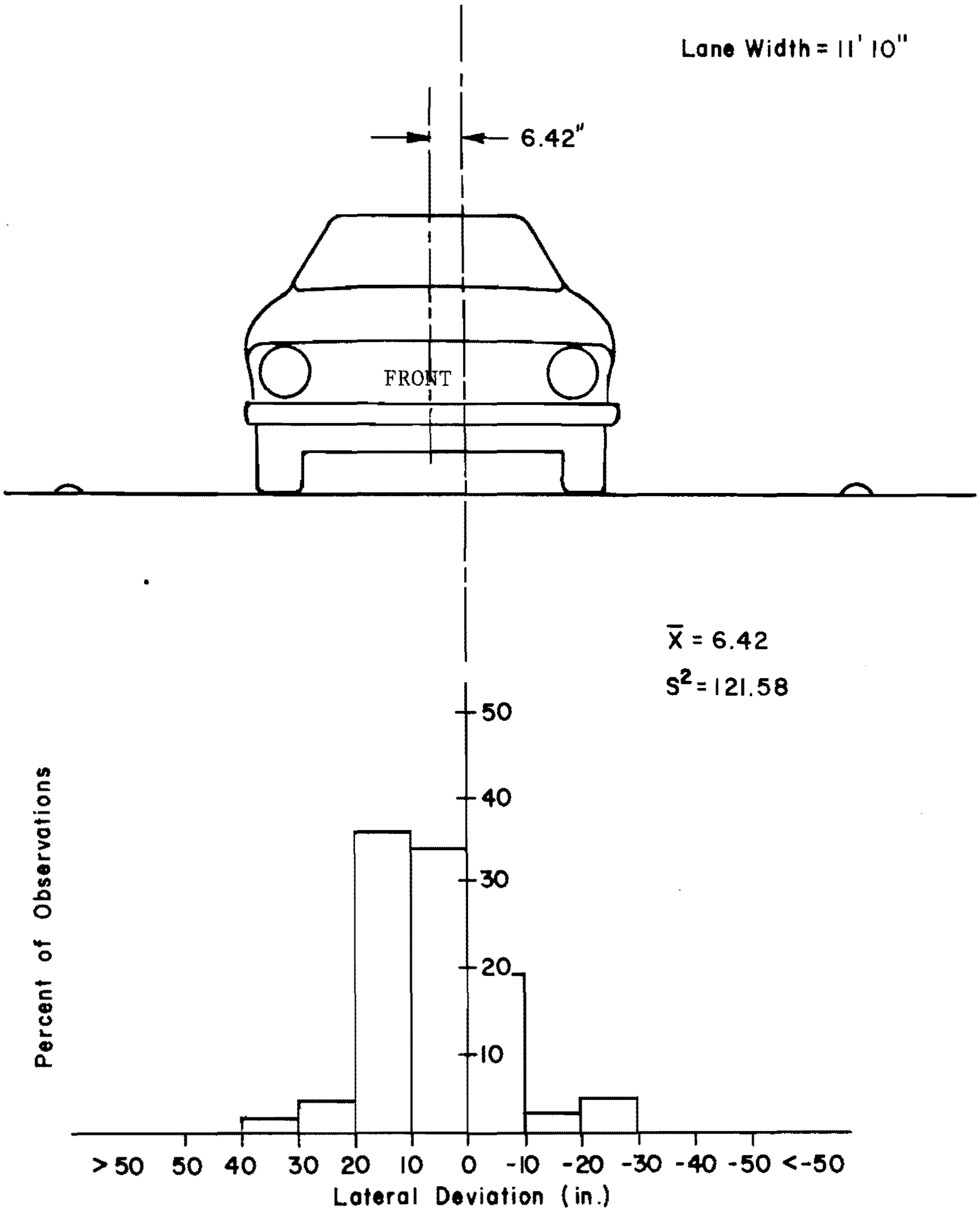


Fig C.36. Lateral deviations at Denson & Airport.

BARTON SPRINGS AND LAMAR (Austin)

Site Characteristics

The site is located on Lamar Blvd. south of Barton Springs Road. It is a five-lane facility with a CTWLTML in the center. The average daily traffic is 29,940 and the volume during the time of data collection is shown in Table C.7.

The posted speed limit is 40 mph; the markings are white dash lines with white buttons (3" diameter) on through lanes and left-turn lanes. A raised barrier was installed at the intersection approach. The width of the left-turn lane is 13'5", with through lane widths ranging from 11'4" to 12'1". The land use at the site consists of a bowling center, service station, and automobile repair shops with driveways scattered along the section (Fig C.37).

Personal Observation

No conflicts were observed during the study period. There were only seven left turns into the bowling cetner during the offpeak observation and none during the peak period. However, a few vehicles turned left into or out of the service station, which caused minor problems to the through traffic.

Lateral Placement

Lateral placement of vehicles at the approach to Barton Springs is illustrated in Fig C.38. The average displacement is 19.48 inches to the left of the center line of the left-turn lane.

Entrance Distance

Entrance distance during offpeak and evening peak periods is shown in Fig C.39. The average entrance distances were 277.5 feet and 299.5 feet, respectively.

TABLE C.7. VOLUME DATA AT BARTON SPRINGS AND LAMAR

	Lanes 1&2	Intersection Left turn	Lane 4	Lane 5
9:00	164	12	127	130
9:15	156	9	78	103
9:30	185	26	93	134
9:45	187	17	79	115
Total	692	64	377	482
Rate	173	16	94	121
3:45	284	11	66	65
4:00	368	27	94	88
4:15	267	12	88	88
4:30	314	24	95	119
4:45	390	17	112	146
Total	1623	91	455	506
Rate	325	18	91	101

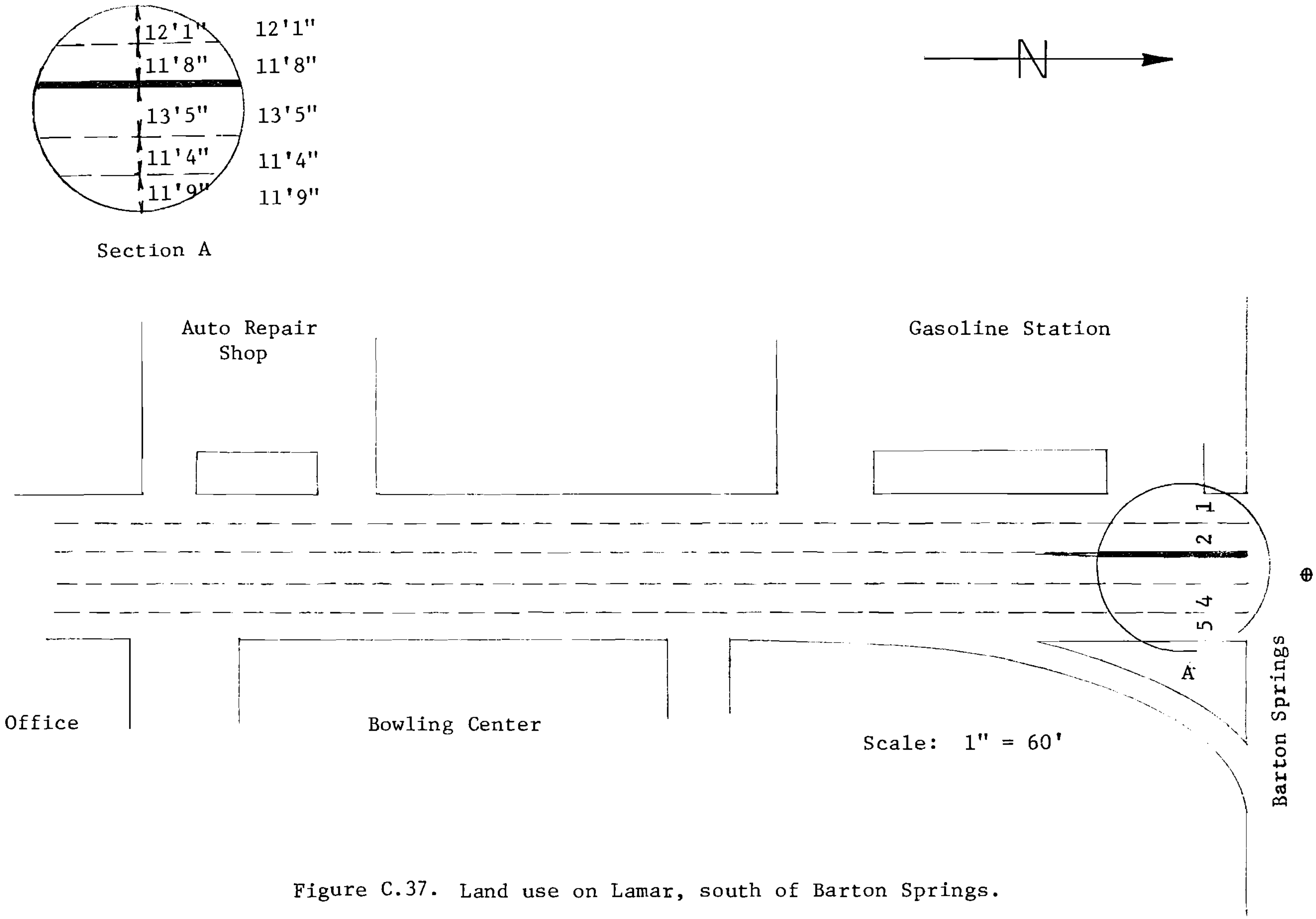


Figure C.37. Land use on Lamar, south of Barton Springs.

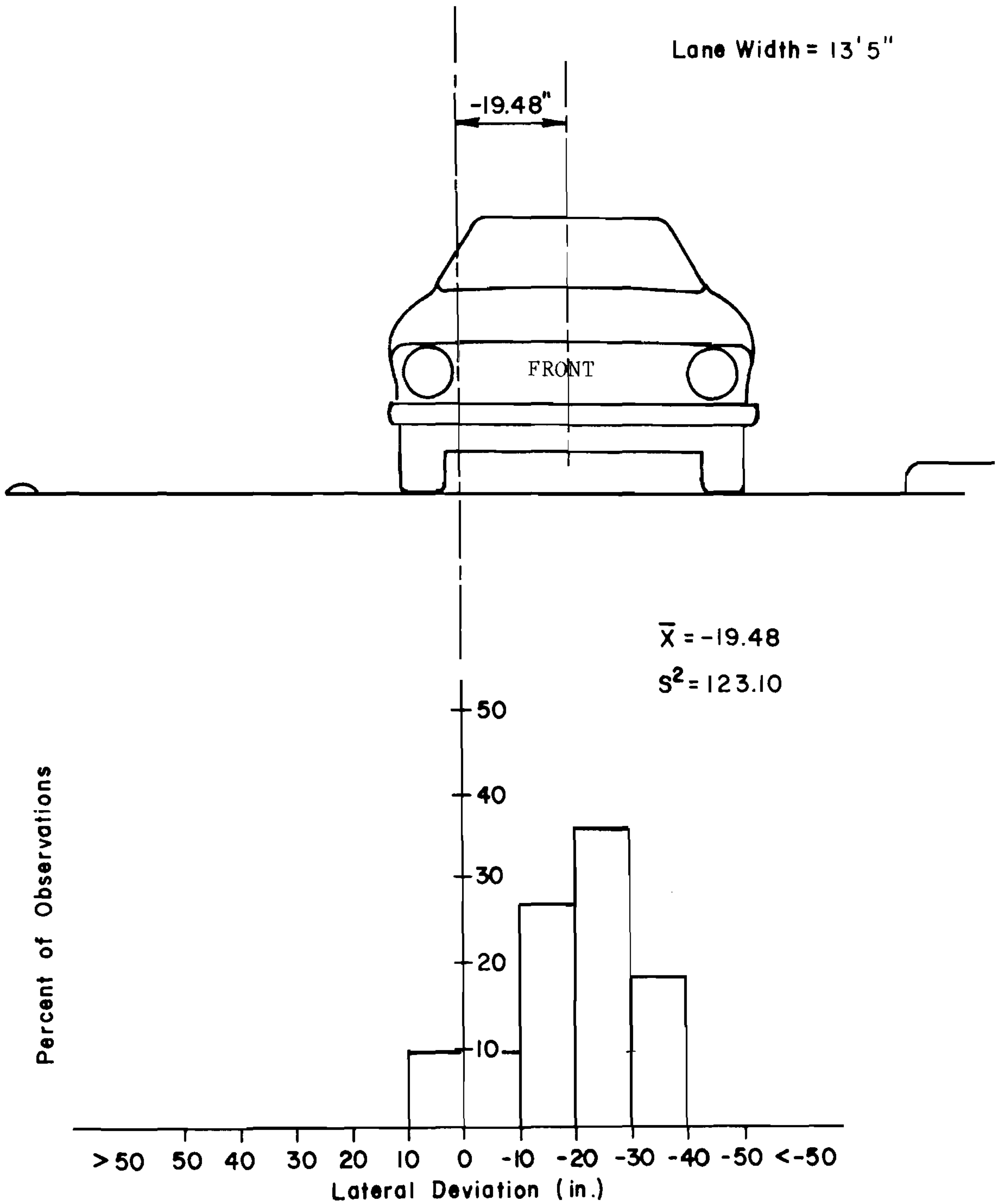
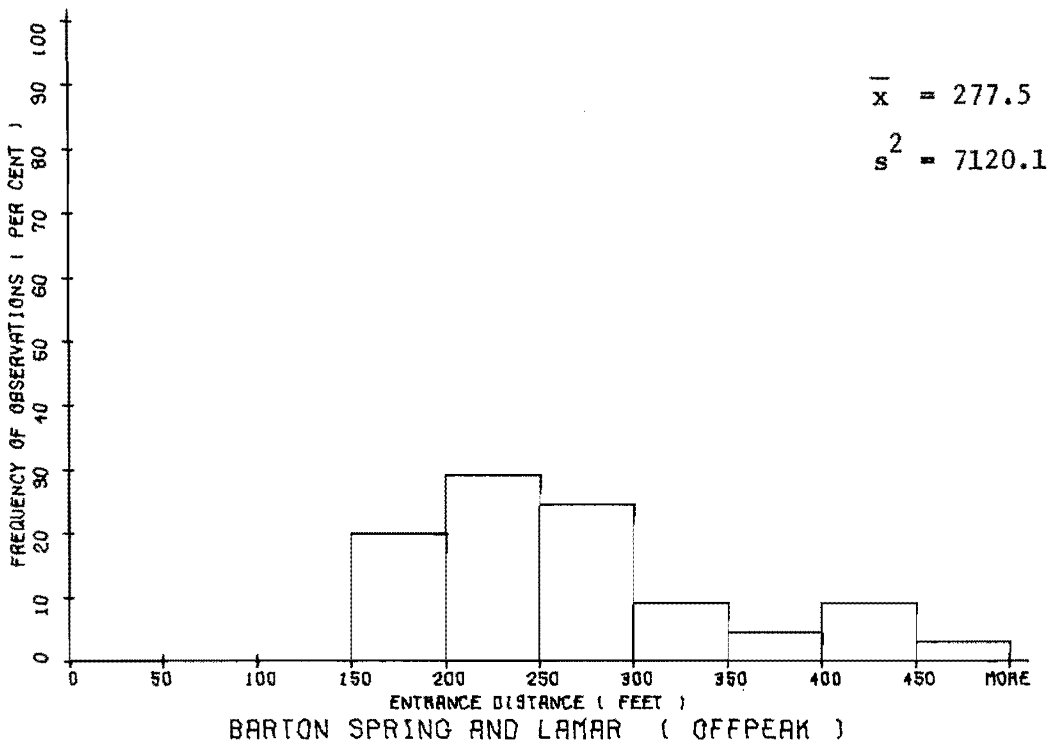


Fig C.38. Lateral deviation at Barton Springs & Lamar.



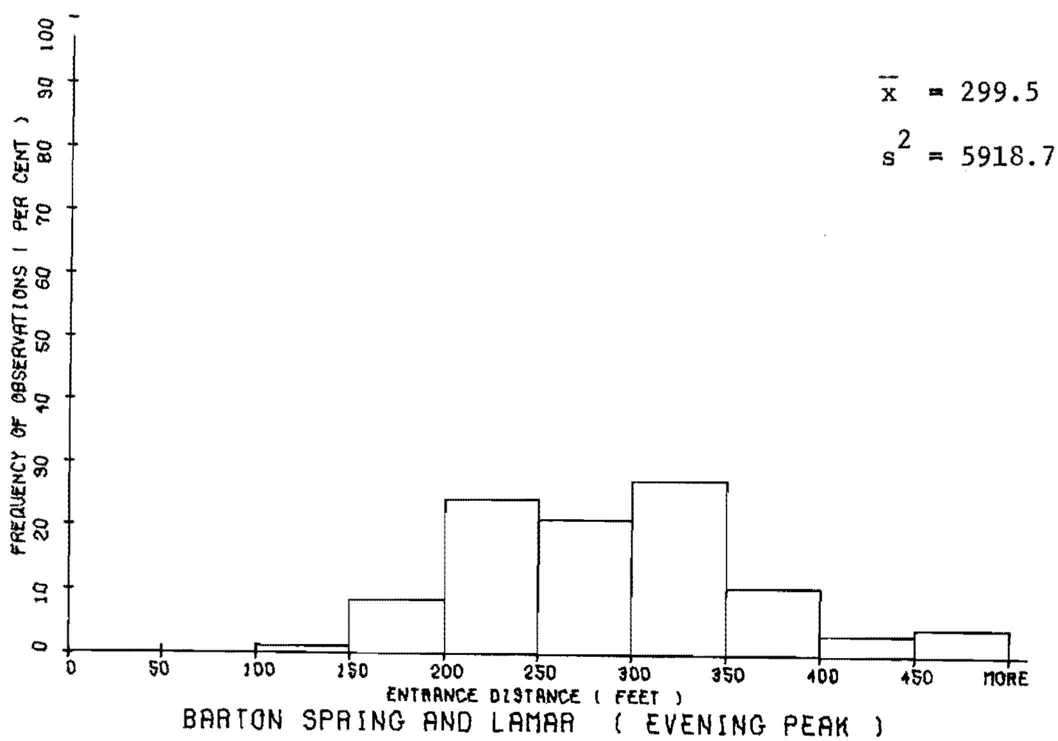


Fig C.39. Entrance distance at Barton Springs & Lamar.

Maneuvering Distance

Maneuvering distance during offpeak and evening peak periods is shown in Fig C.40. The average maneuvering distance was 66.9 feet and 62.8 feet, respectively.

RIVERSIDE AND CONGRESS (Austin)

Site Characteristics

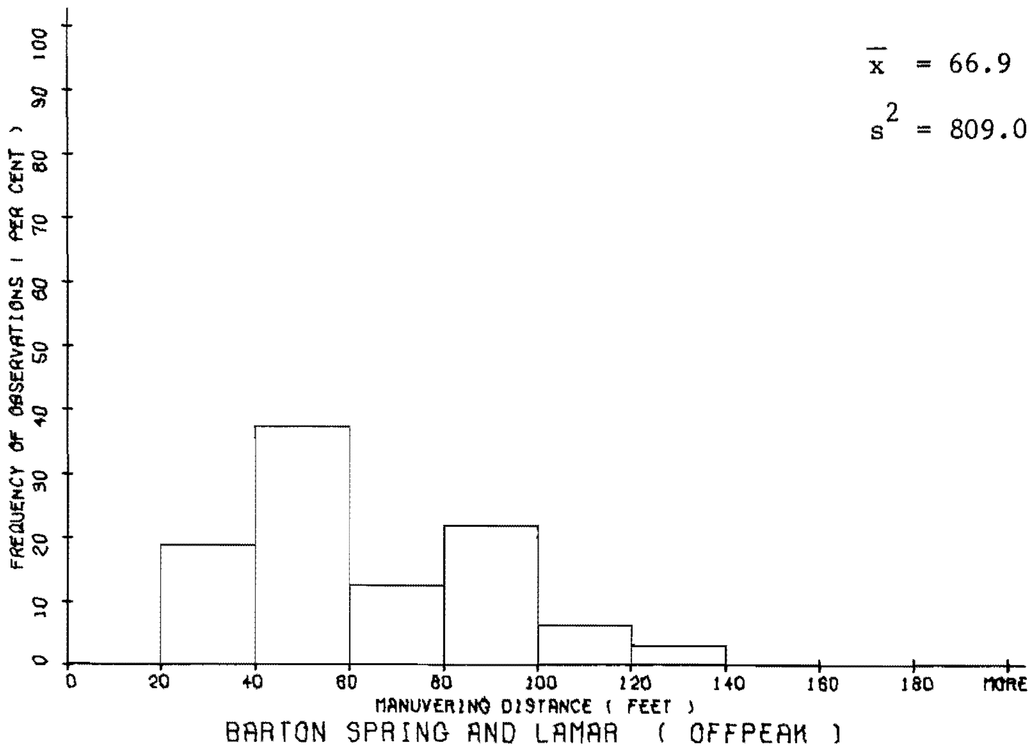
The site is located on Congress Ave. south of Riverside Drive. It is a seven-lane facility with a CTWLTML at midblock and a COWLTML at the intersection approach. The average daily traffic at the site is 21,340 and the volume during the time of data collection is shown in Table C.8.

The posted speed limit is 35 mph; the markings are standard CTWLTML marking at midblock and flush COWLTML marking at the intersection approach, with square buttons on both sides of the lane. The storage length is approximately 140 feet and an opening of about 125 feet is provided for entry. The width of the left-turn lane is 11 feet with through lane width ranges from 9'11" to 10'8"; an additional 10 feet is provided on one side of the street for parking.

The land uses at the site are service station, restaurant, and office buildings. A sign with the name of the crossing street is posted on the side of the street before the intersection to provide advance indication of the intersection (Fig C.41.)

Personal Observation

The site is the only seven-lane facility with a continuous two-way left-turn median lane in the center. During the offpeak period, there was moderate left turn volume, which utilized the left-turn lane very well. Few left turns into the office building next to the restaurant were observed; this caused some problems to the through traffic, but no major conflicts occurred.



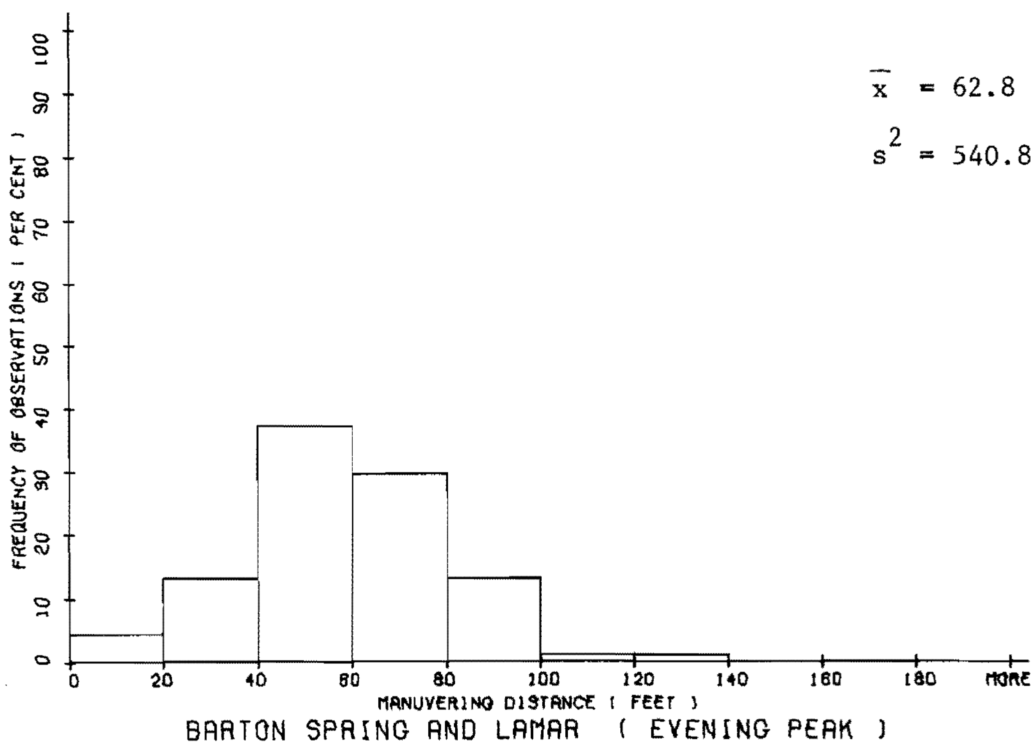


Fig C.40. Maneuvering distance at Barton Springs & Lamar.

TABLE C.8. VOLUME DATA AT RIVERSIDE AND CONGRESS

	Lanes 1,2,&3	Intersection Left turn	Lanes 5,6,&7
2:00	203	48	139
2:15	183	56	136
Total	386	104	275
Rate	193	52	138
5:10	123	29	44
5:15	369	74	106
Total	492	103	150
Rate	295	73	90

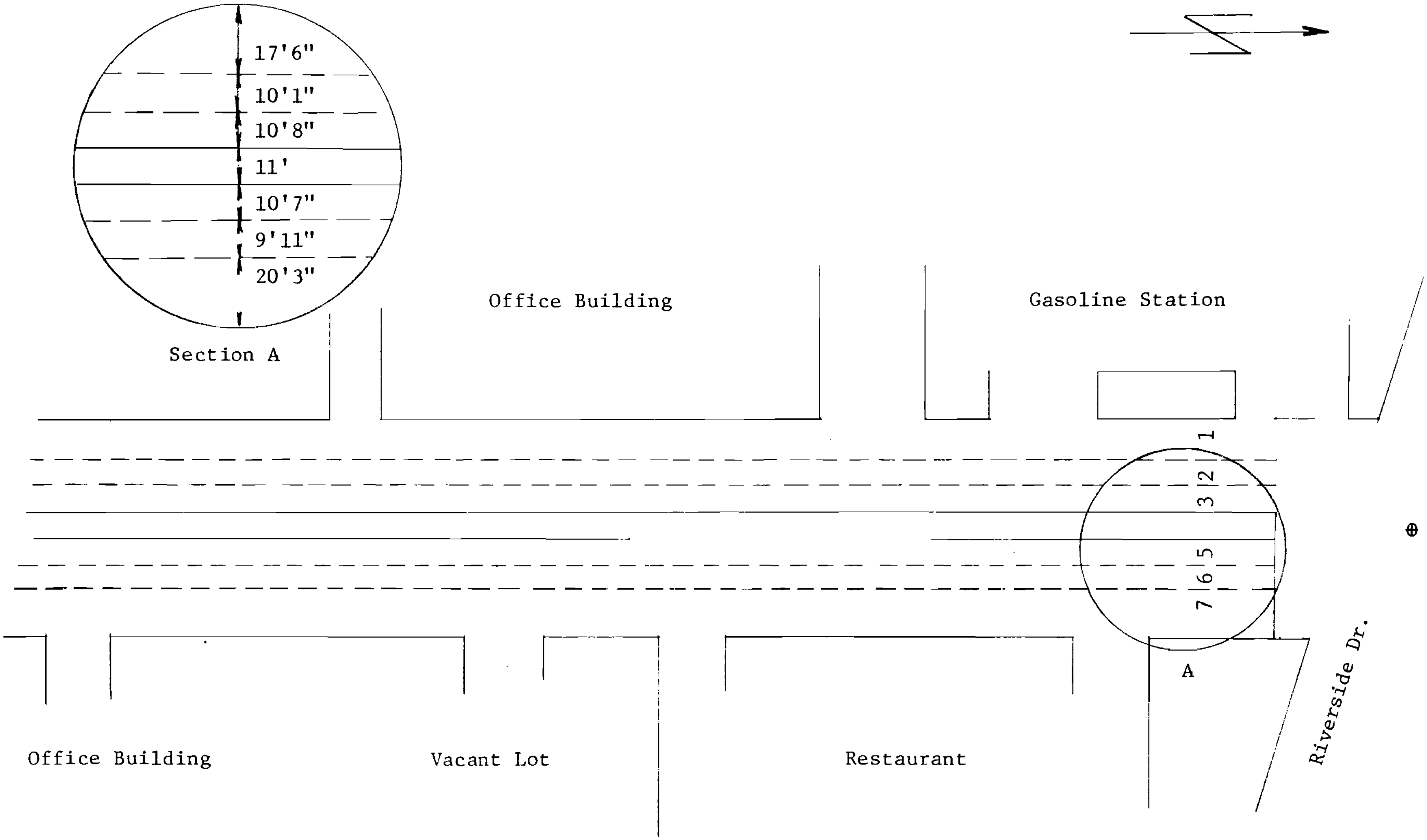


Figure C.41. Land use on Congress, south of Riverside.

During the evening peak period, there was high demand for left turns at the intersection which the left-turn phase is incapable of handling in some cases. The queue length sometimes ended at about 300 feet from the intersection, thus forcing the left-turn vehicles to enter the left-turn lane before reaching the opening provided for entry. Although a long queue existed during the evening peak period, no major conflicts were observed.

Lateral Placement

Lateral placement of vehicles at the approach to Riverside is illustrated in Fig C.42. The average displacement was 8.10 inches to the right of the center line of the left-turn lane.

Entrance Distance

The entrance distance during offpeak and evening peak periods is shown in Fig C.43. The average entrance distances during those periods were 269.4 feet and 374.6 feet, respectively.

Maneuvering Distance

The maneuvering distance during offpeak and evening peak periods is shown in Fig C.44. The average maneuvering distances during those periods were 48.2 feet and 36.6 feet, respectively.

45TH AND LAMAR--SOUTHBOUND (Austin)

Site Characteristics

The site is located on Lamar Street north of 45th Street. It is a four-lane facility with a raised COWLTML at the intersection approach. The average daily traffic at the site is 21,680. The posted speed limit is 40 mph; the markings are typical COWLTML markings. The width of the left-turn lane is 11'2" and the land use is mostly residential.

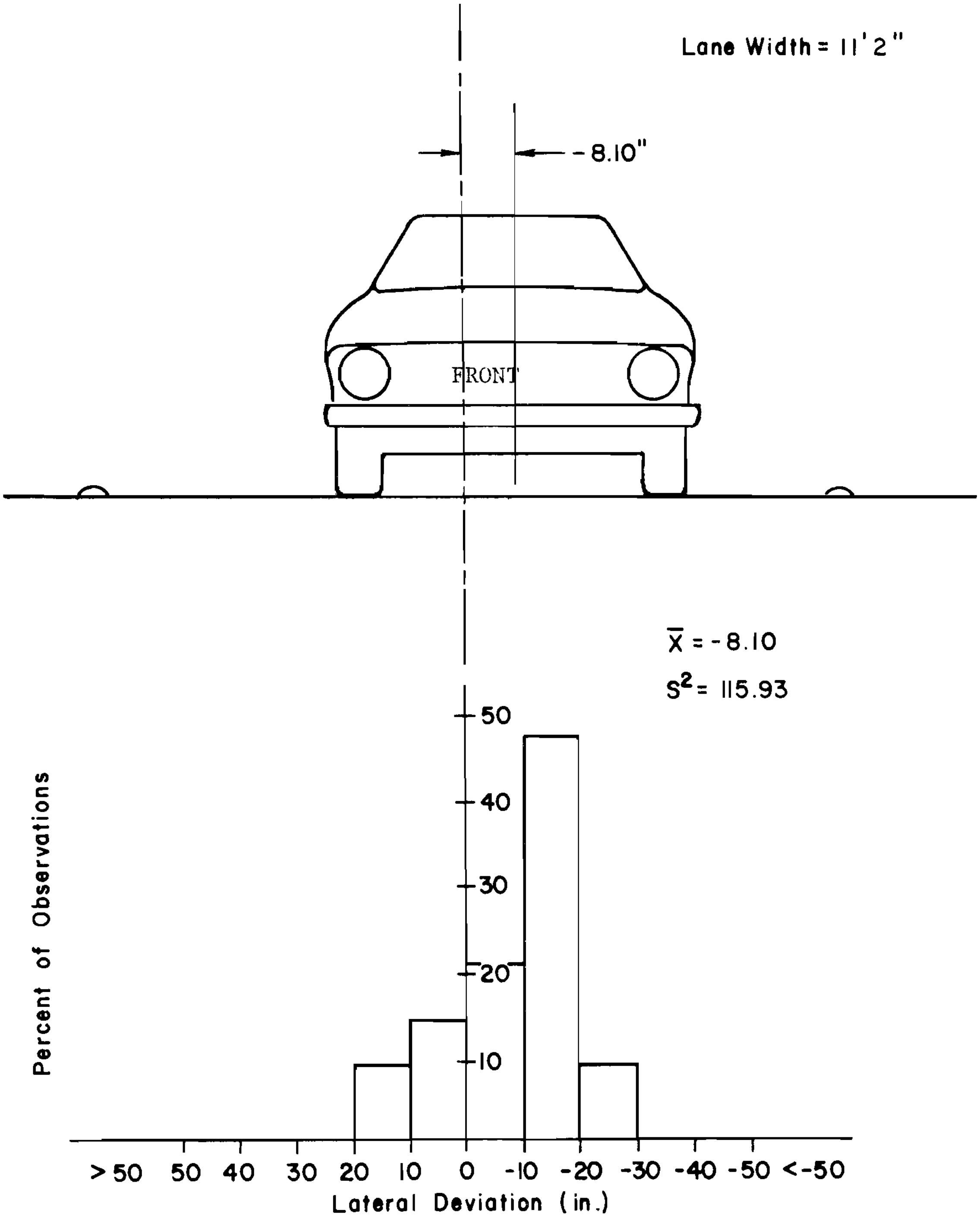
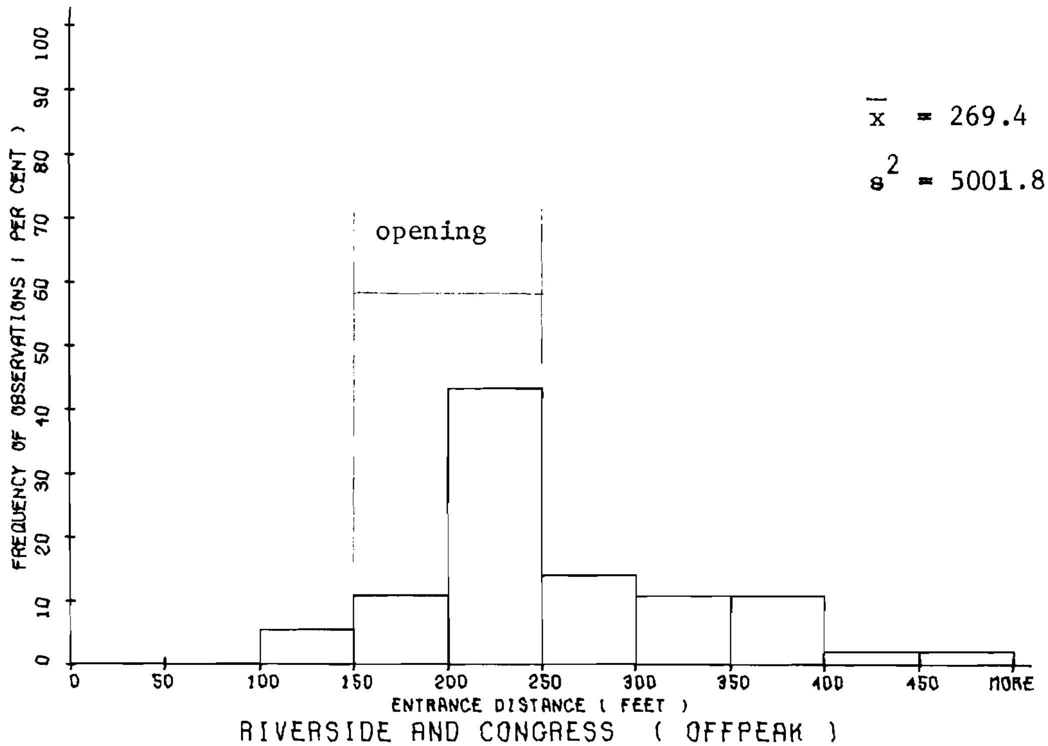


Fig C.42. Lateral deviation at Riverside & Congress.



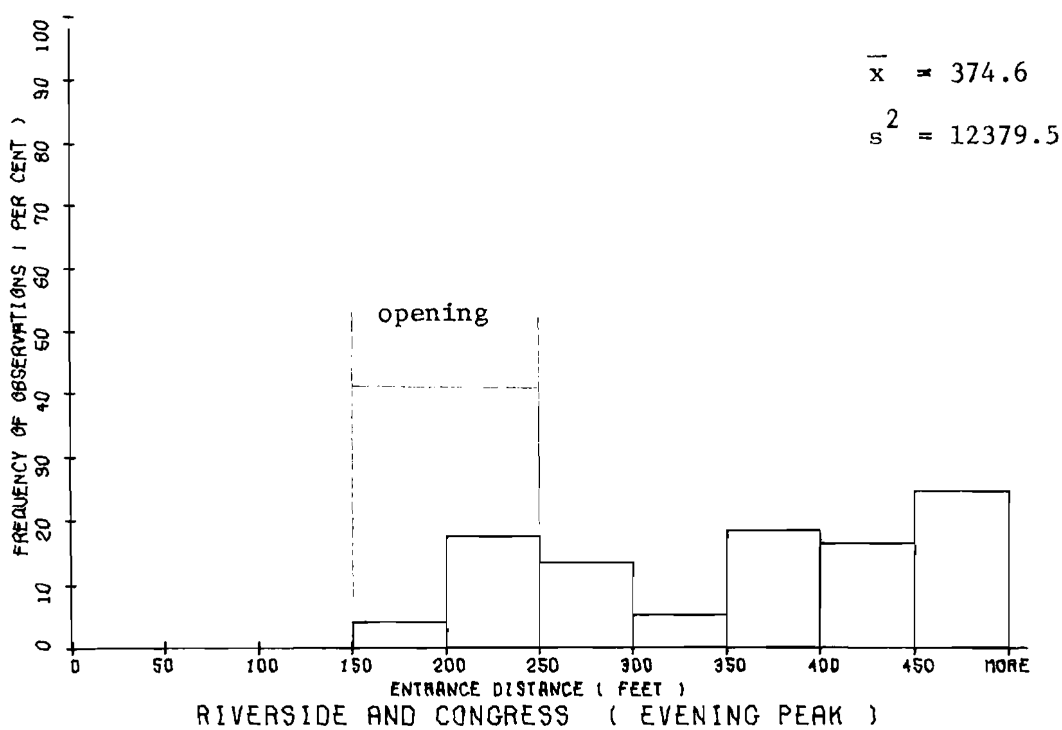
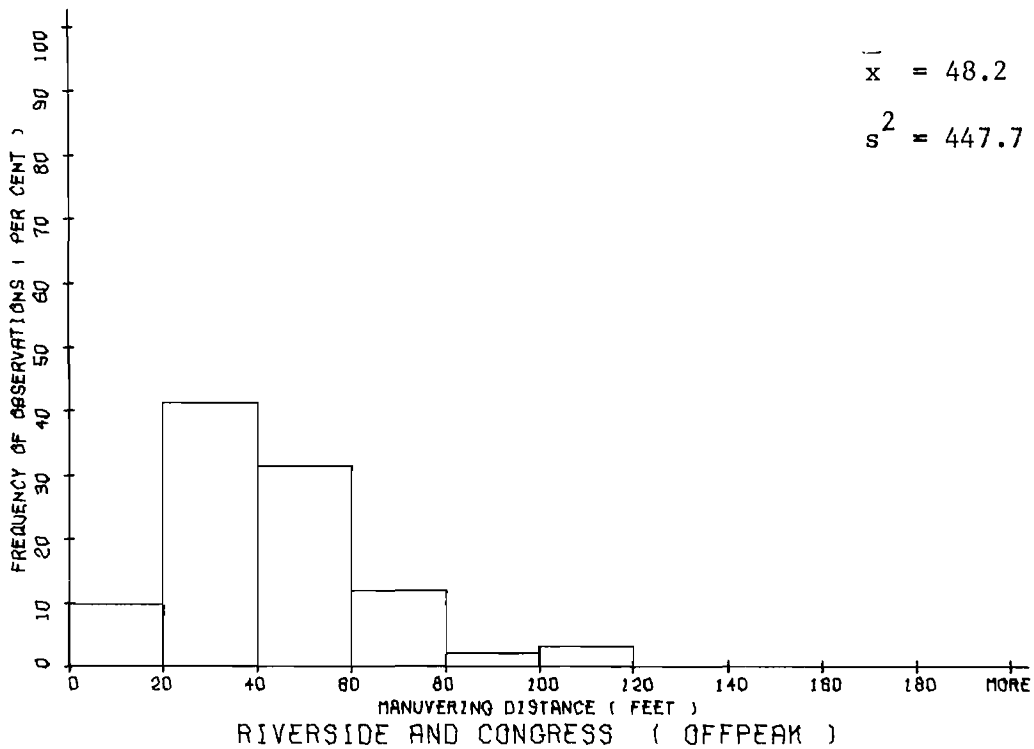


Fig C.43. Entrance distance at Riverside & Congress.



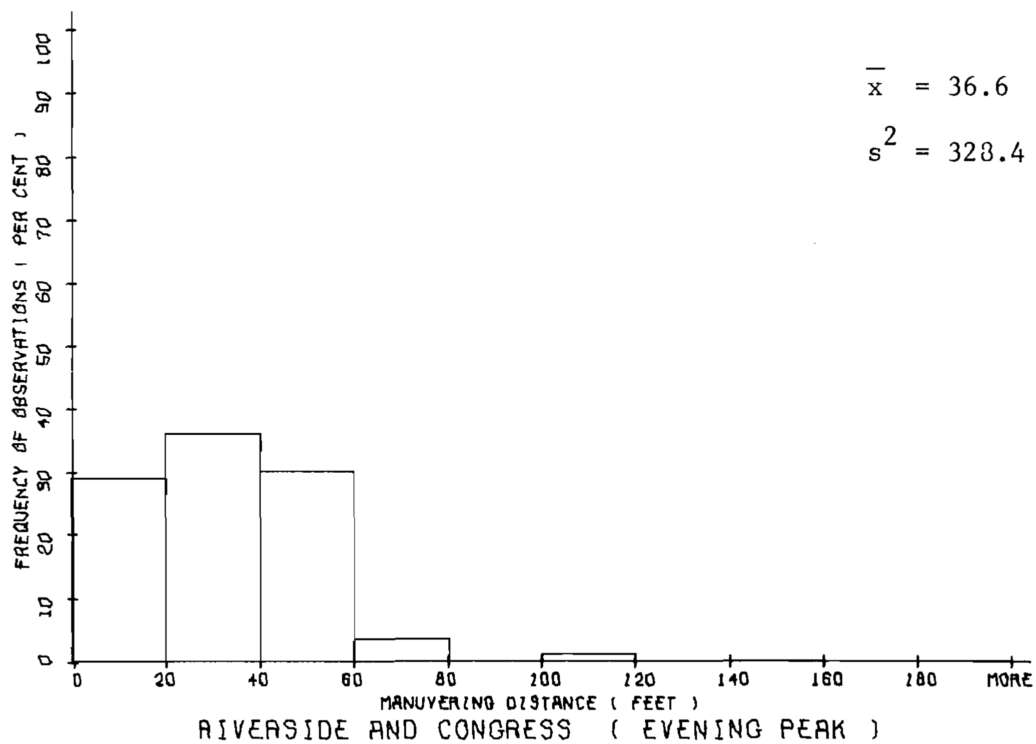


Fig C.44. Maneuvering distance at Riverside & Congress.

Lateral Placement

Lateral placement of vehicles at the approach to 45th Street is illustrated in Fig C.45. The average displacement was 7.56 inches to the right of the center line of the left-turn lane.

MARTIN LUTHER KING, JR. BLVD. AND LAMAR (Austin)

Site Characteristics

The site is located on Lamar Blvd. north of Martin Luther King, Jr. Blvd. It is a T intersection with four through lanes and a raised COWLTML at the intersection approach. The location of the raised island is between the left-turn lane and the adjacent through lane. The average daily traffic at the site is 25,790. The posted speed limit is 35 mph and the width of the left-turn lane is 11'6". Lane uses at the site are office buildings and recreational areas.

Lateral Placement

Lateral placement of vehicles at the approach to Martin Luther King, Jr. Blvd. is illustrated in Fig C.46. The average displacement was 20.62 inches to the right of the center line of the left-turn lane.

45TH AND GUADALUPE--SOUTHBOUND (Austin)

Site Characteristics

The site is located on Guadalupe Street north of 45th Street. It is a four-lane facility with a flush COWLTML at the intersection approach. The average daily traffic at the site is 20,730. The posted speed limit is 35 mph, and the markings are standard COWLTML. The width of the left-turn lane is 10'6" and the land uses are residential and vacant areas.

Lateral Placement

Lateral Placement of vehicles at the approach to 45th Street is illustrated in Fig C.47. The average displacement was .22 inches to the left of the center line of the left-turn lane.

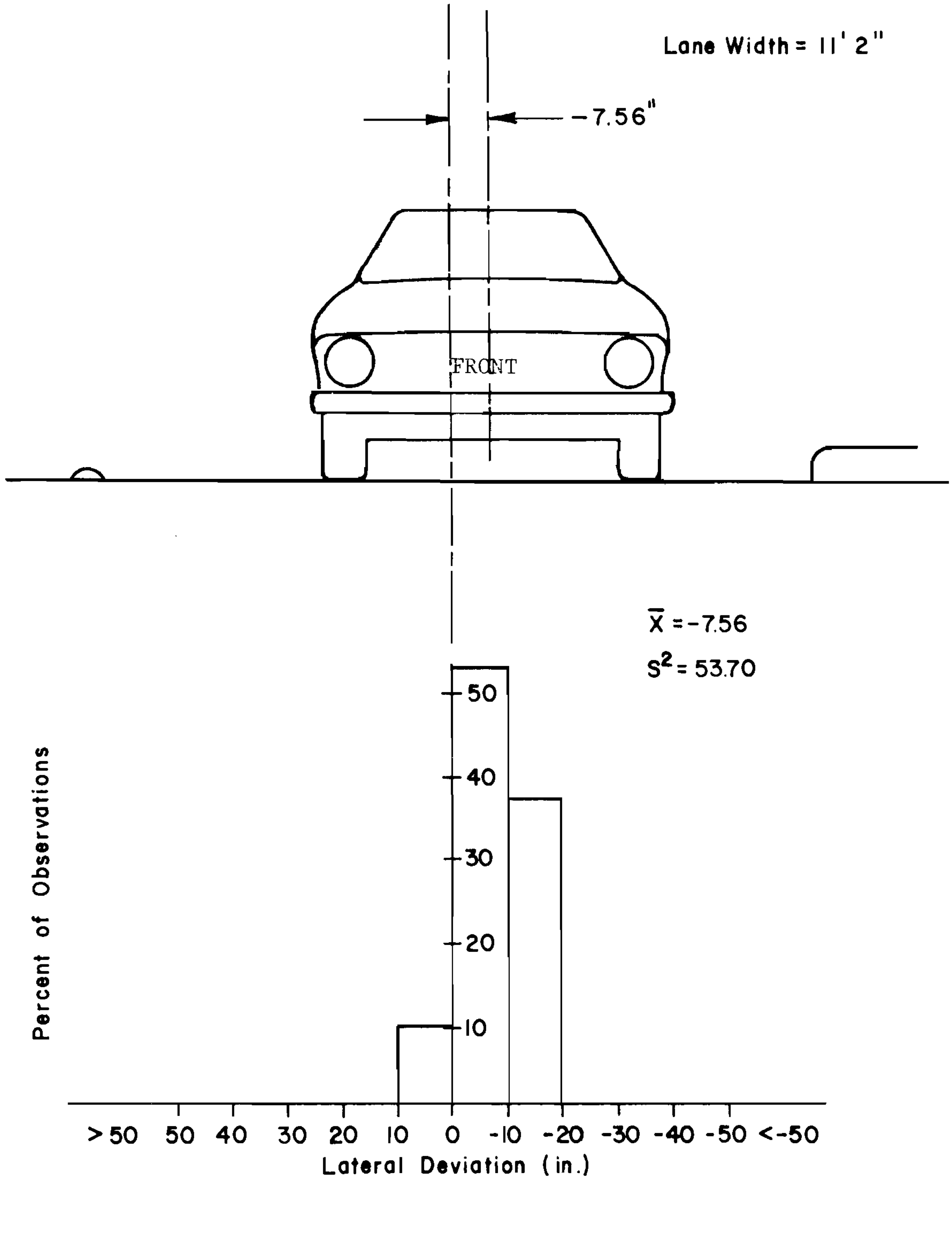


Fig C.45. Lateral deviations at 45th & Lamar (southbound).

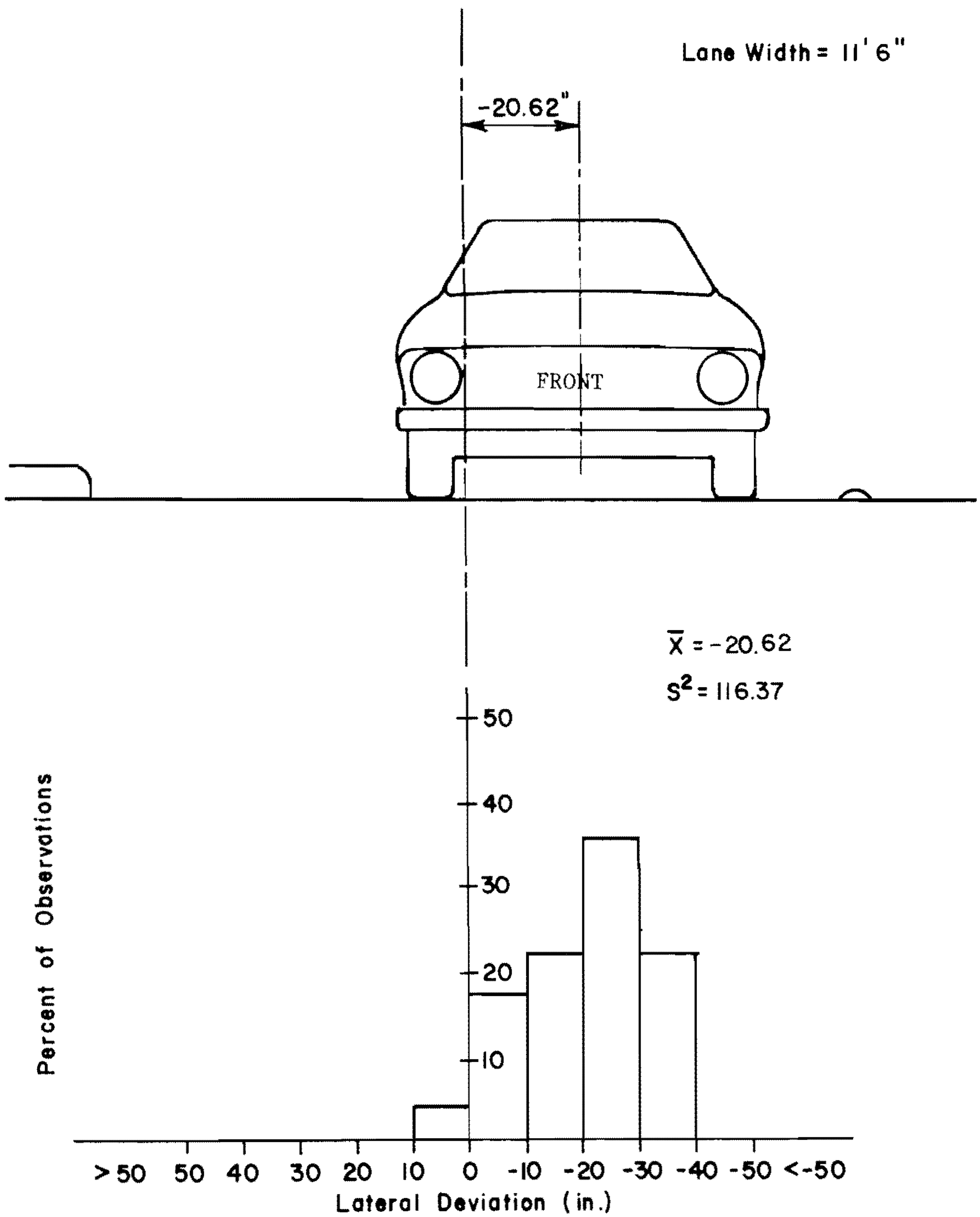


Fig C.46. Lateral deviation at Martin Luther King, Jr Blvd. & Lamar.

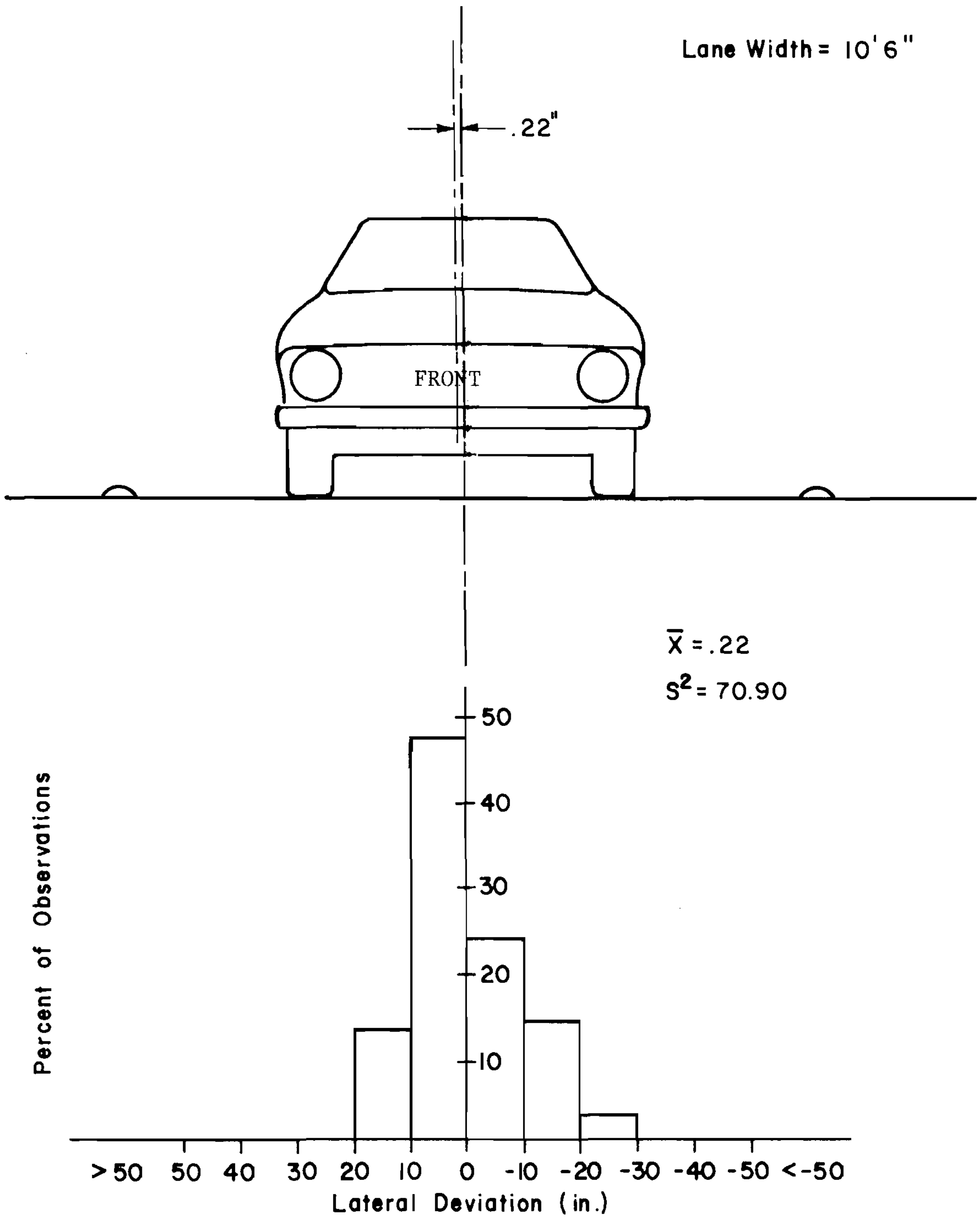


Fig C.47. Lateral deviation at 45th & Guadalupe (southbound).

CONGRESS AND MARTIN LUTHER KING, JR. BLVD. (Austin)

Site Characteristics

The site is located on Martin Luther King, Jr. Blvd. west of Congress Avenue. It is a four-lane facility with a flush COWLTML at the intersection approach. The average daily traffic at the site is 25,040. The posted speed limit is 30 mph, and the lane marking is standard COWLTML with buttons. The width of the left-turn lane is 12'4" and the land use is parking lots and the University of Texas.

Lateral Placement

Lateral placement of vehicles at the approach to Congress Avenue is illustrated in Fig C.48. The average displacement was 2.36 inches to the right of the center line of the left-turn lane.

COCKRELL AND BERRY (Fort Worth)

Site Characteristics

The site is located on Berry Street east of Cockrell Street. It is a seven-lane facility with a CTWLTML in the center. The average daily traffic at the site is 19,500 and no signal exists at this intersection.

The posted speed limit is 35 mph, and the markings are standard CTWLTML with a single row of buttons at midblock and double rows at the intersection approach. The width of the left-turn lane is 15'3" and the land use is all commercial.

Lateral Placement

Lateral placement of vehicles at the approach to Cockrell Street is illustrated in Fig C.49. The average displacement was 21.60 inches to the left of the center line of the left-turn lane.

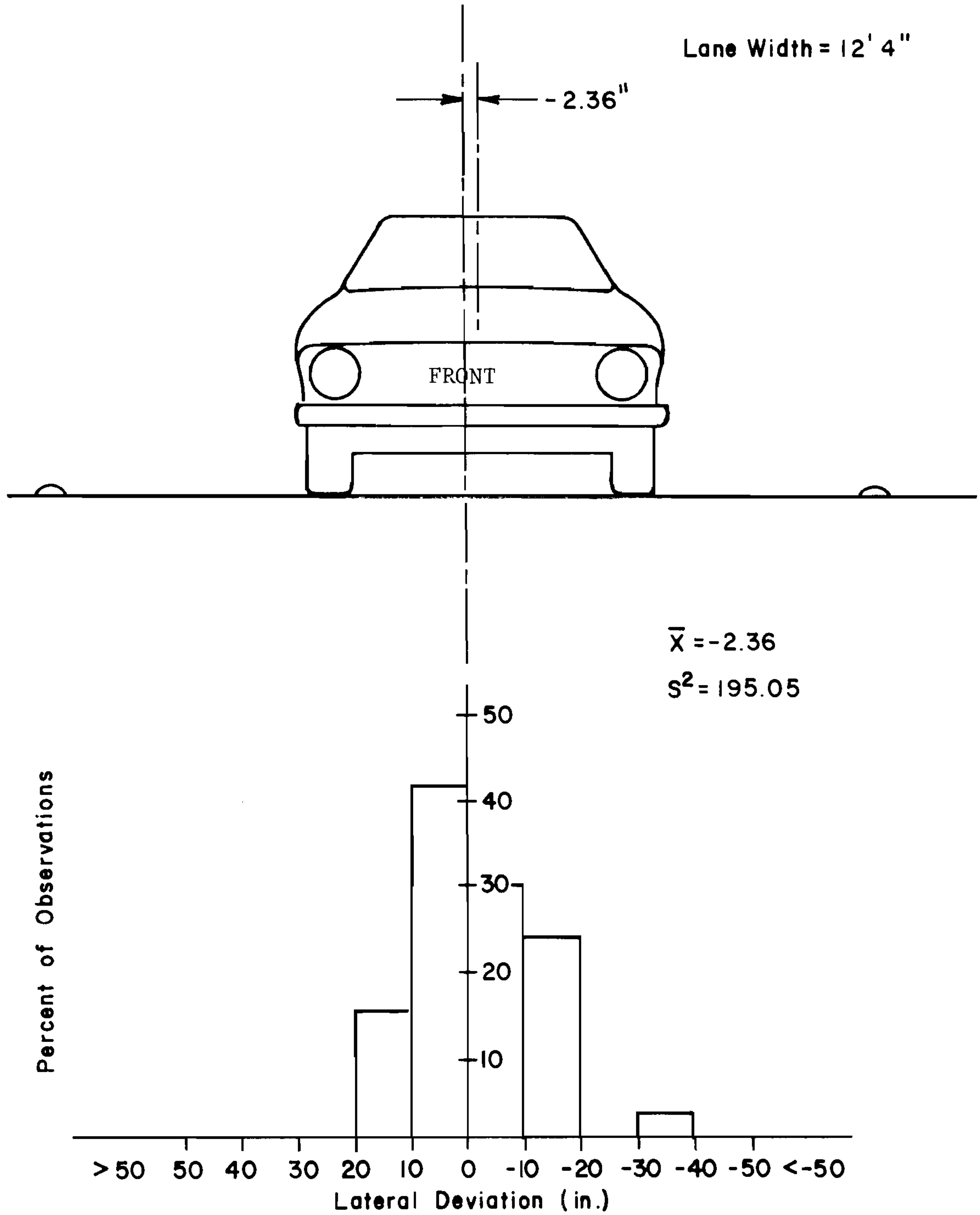


Fig C.48. Lateral deviation at Congress & Martin Luther King, Jr. Blvd.

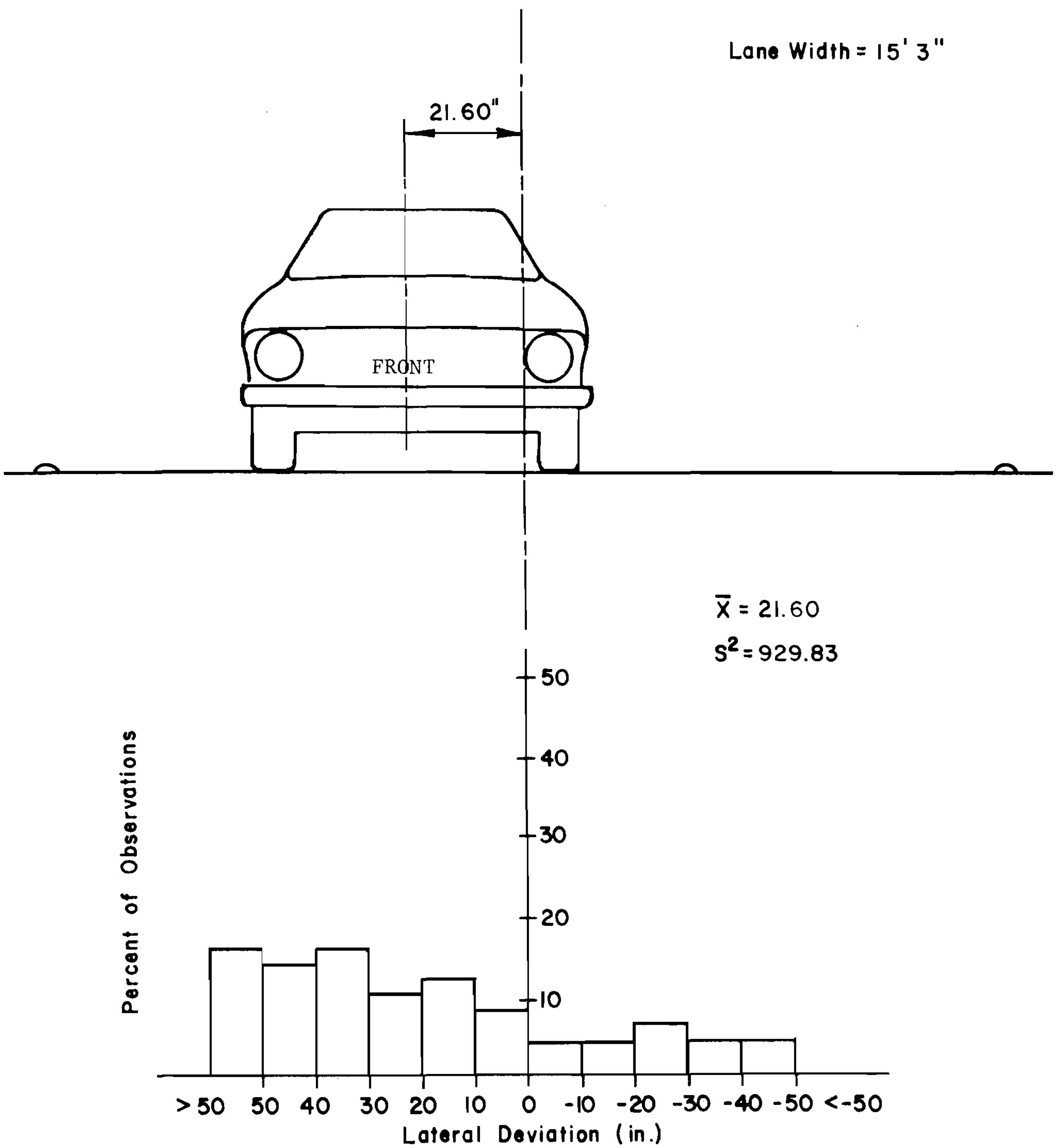


Fig C.49. Lateral deviation at Cockrell & Berry.

WICHITA AND MANSFIELD (Fort Worth)

Site Characteristics

The site is located on Mansfield Highway east of Wichita Street. It is a four-lane facility with a raised COWLTML installed at the intersection approach. The average daily traffic at the site is 14,500. The posted speed limit is 40 mph, and 12-inch-diameter metallic buttons are used as markings on the opposite side of the raised island. The width of the left-turn lane is 11'10" and the land use is mostly commercial.

Lateral Placement

Lateral placement of vehicles at the approach to Wichita is illustrated in Fig C.50. The average displacment was 2.77 inches to the left of the center line of the left-turn lane.

GULIFORD AND CAMP BOWIE (Fort Worth)

Site Characteristics

The site is located on Camp Bowie Boulevard east of Guliford Street and is only a few blocks from the previous site. It is a six-lane facility with a raised COWLTML installed in the center. The average daily traffic at the site is 32,000. The posted speed limit is 35 mph, and 8-inch-diameter ceramic buttons over a painted line are used as markings on the opposite side of the raised island. The width of the left-turn lane is 10'6", and the land use is a commercial shopping center.

Personal Observation

Since land use along Camp Bowie Blvd. is commercial and retail stores, a high gerenation rate of left-turns is experienced at midblock and at intersections. The operating speed seemed to be high, and frequent sudden stops were required by the motorists at the signalized intersection. U-turns were common at midblocks and intersections where openings are provided for left turns.

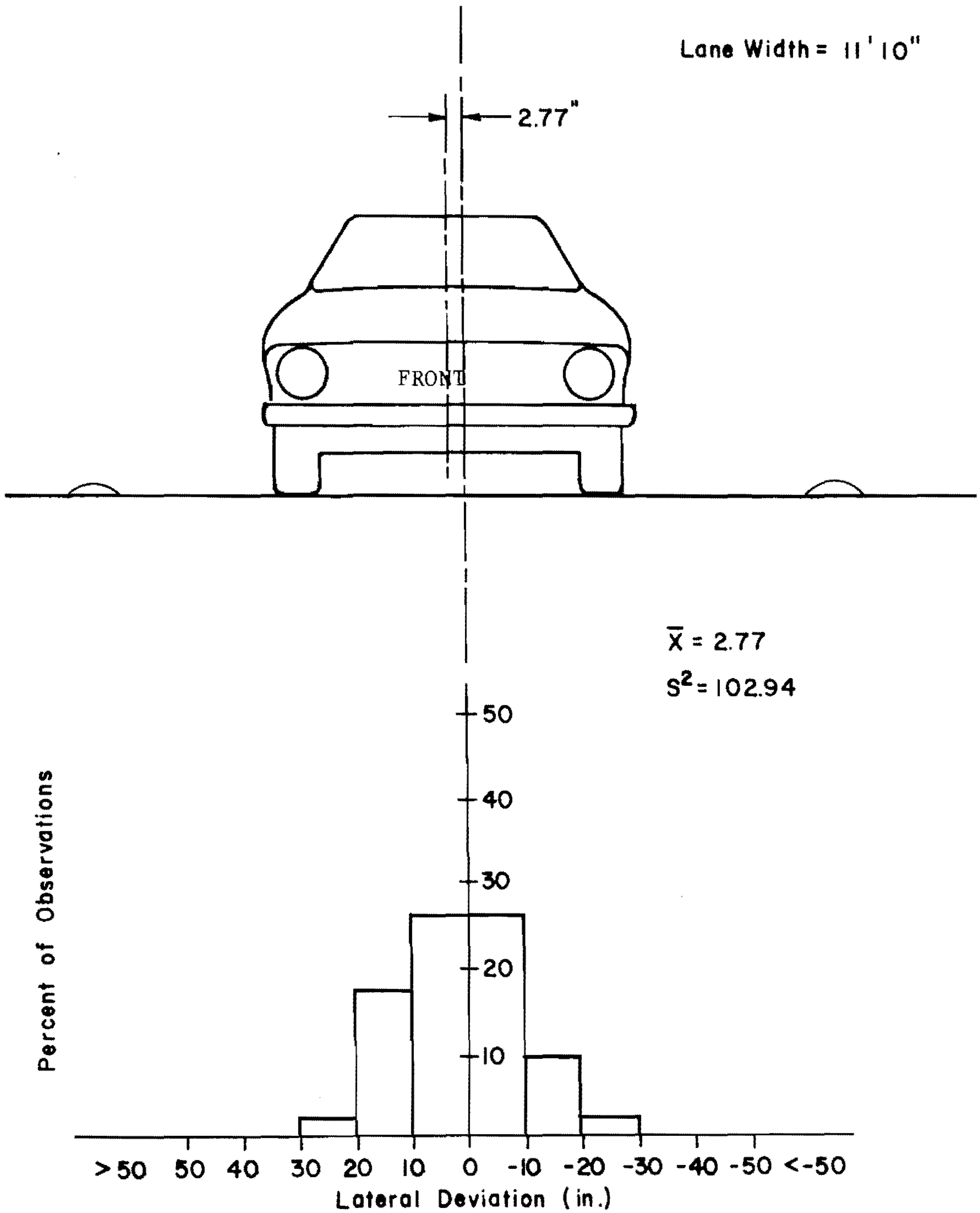


Fig C.50. Lateral deviation at Wichita & Mansfield.

Lateral Placement

Lateral placement of vehicles at the approach to Guliford is illustrated in Fig C.51. The average displacement was 5.97 inches to the left of the center line of the left-turn lane.

UNIVERSITY AND WHITE SETTLEMENT (Fort Worth)

Site Characteristics

The site is located on White Settlement Road west of University Drive. It is a four-lane facility with a COWLTML at the intersection approach. The average daily traffic at the site is 16,700. The posted speed limit is 30 mph, and 8-inch-diameter ceramic buttons were installed on both sides of the left-turn lane for delineation. The width of the left-turn lane is 12'1", and the land uses are residential and retail stores.

Lateral Placement

The lateral placement of vehicles at the approach to University is illustrated in Fig C.52. The average displacement was 6.64 inches to the left of the center line of the left-turn lane.

VICKERY AND MAIN (Fort Worth)

Site Characteristics

The site is located on South Main Street north of East Vickery Blvd. It is a four-lane facility with a COWLTML at the intersection approach. THe average daily traffic at the site is 8,000. The speed limit was not posted at the site but was assumed to be 30 mph. 12-inch-diameter metallic buttons were installed on both sides of the left-turn lane. The left-turn lane is 11'2" and the adjacent land use is mostly industrial.

Lateral Placement

The lateral placement of vehicles at the approach to Vickery is illustrated in Fig C.53. The average displacement was 3.03 inches to the right of the center line of the left-turn lane.

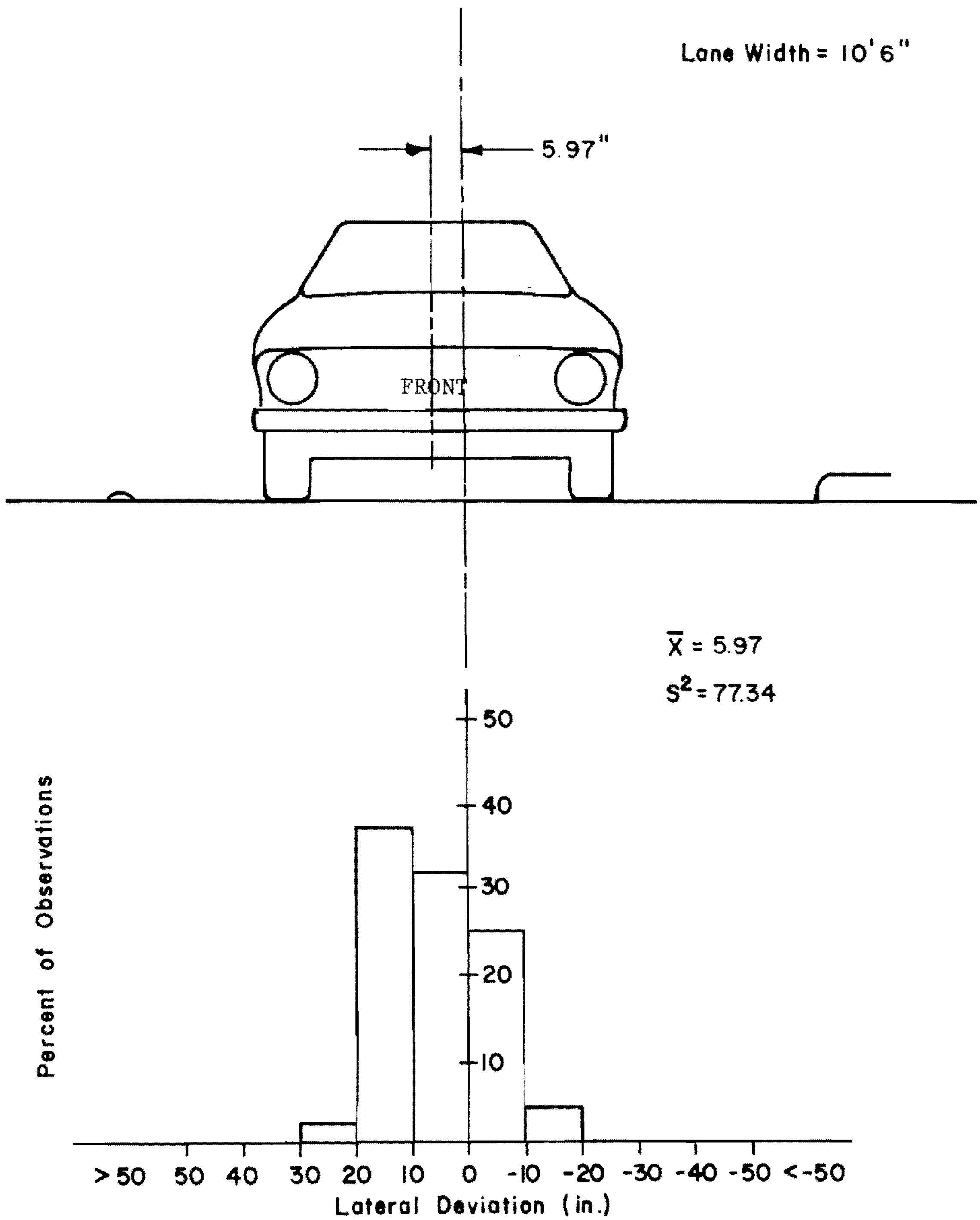


Fig C.51. Lateral deviation at Guliford & Camp Bowie.

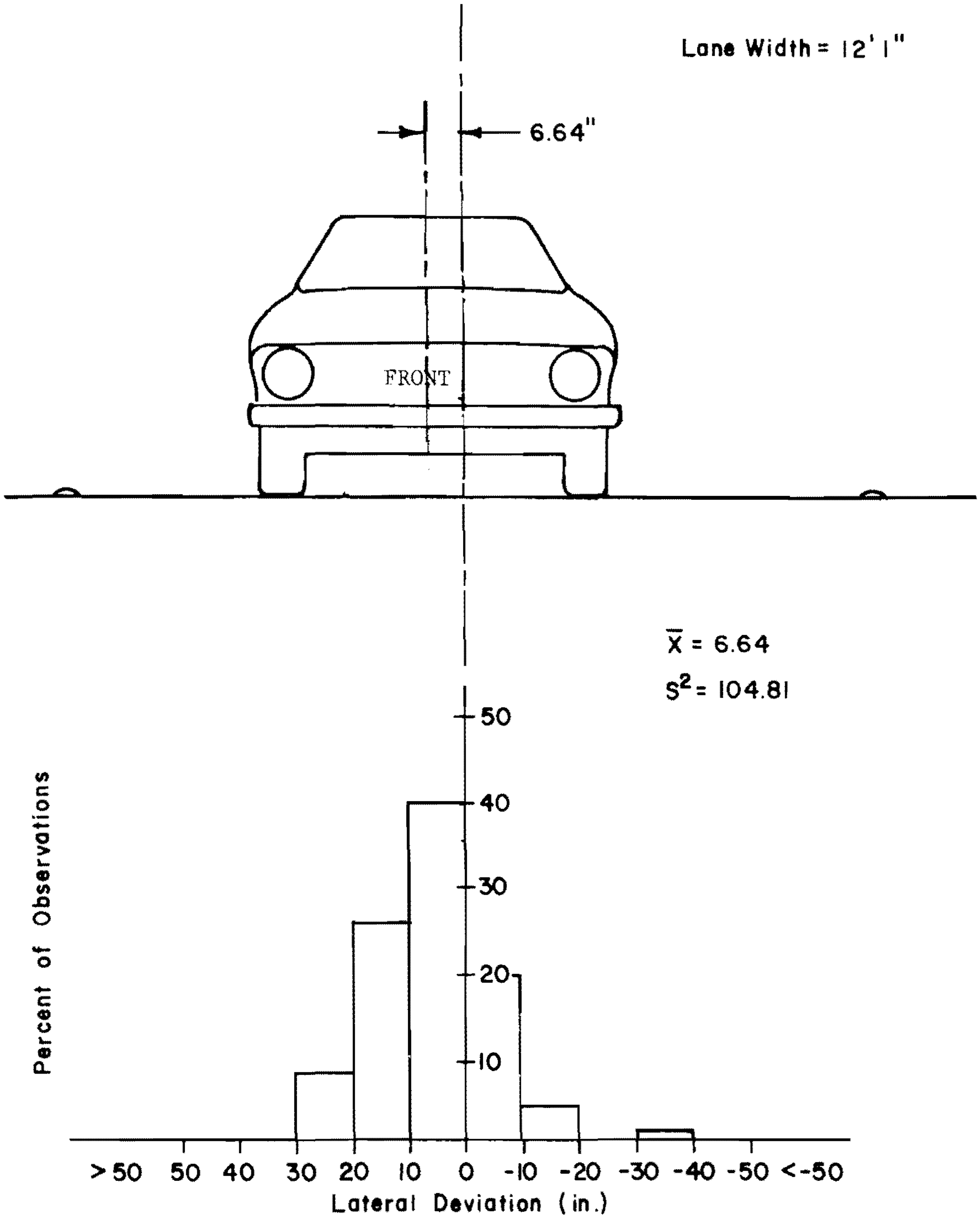


Fig C.52. Lateral deviation at University & White Settlement.

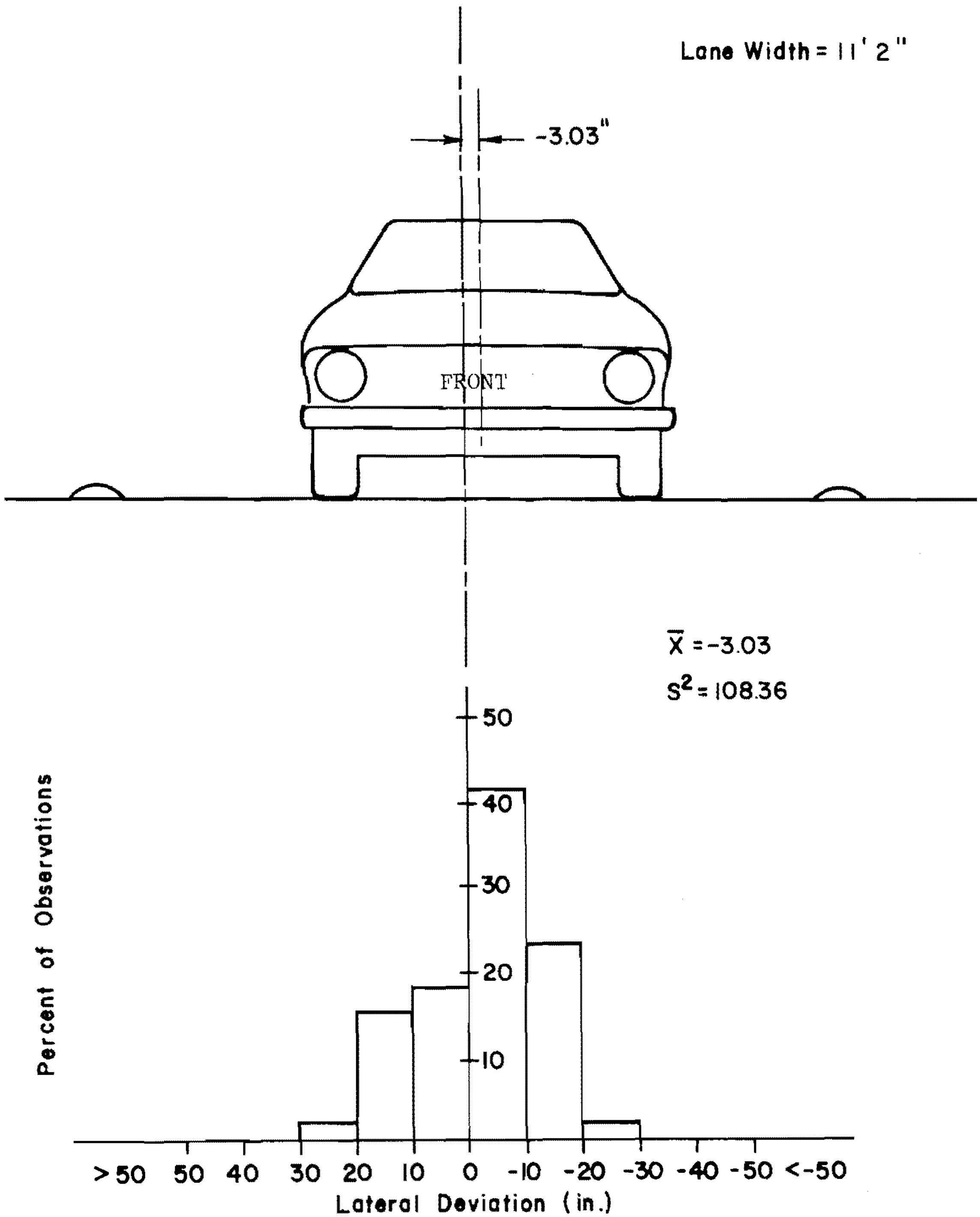


Fig C.53. Lateral deviation at Vickery & Main.