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DEVELOPMENT, EVALUATION AND APPLICATION OF LEFT TURN SIGNAL WARRANTS

Final Report

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16. Abstract

This study dealt with five types of left turn signal phasing: permissive, leading exclusive, lagging exclusive, leading exclusive/ permissive and lagging exclusive/permissive.

The objectives of this research project were to:

1. develop a research work plan to conduct a statistically valid study for the development of numerical warrants for left turn movements, and
2. prepare a database of available information on signalized intersections and select the intersections to be used in the future study.

This report describes the database of Arizona signalized intersections created in this project, the findings on left turn accident rates for different types of left turn phasing (using a nonrandom sample), results of a validation study of the TEXAS computer simulation model, and presents a research work plan for a future research project.

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Throughout the conduct of the research, several organizations made significant contributions to the project. The project staff wishes to recognize the assistance of those organizations.

- Arizona Transportation Research Center, Arizona Department of Transportation
- Traffic Engineering Section, Highway Division, Arizona Department of Transportation
- Office of Safety and Traffic Operations Research and Development Federal Highway Administration
- Selected local jurisdictions in Arizona

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SI (METRIC) UNIT CONVERSION FACTORS

The material contained in this report is presented in terms of English units. The following factors may be used to convert the measures used in this report to the International System of Units (SI):

1 mile per hour (mph) = 1.6093 kilometer per hour (km/h)

1 km/h = 0.6214 mph

1 inch = 2.54 centimeters

1 centimeter = 0.3937 inches

1 foot = 0.3048 meter

1 meter = 3.2808 feet

1 mile = 1.6093 kilometers

1 kilometer = 0.6214 miles

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CHAPTER 1

INTRODUCTION

This final report presents the results of work on the project entitled "Development, Evaluation and Application of Left Turn Signal Warrants." This project was conducted *to design* a future research project which will lead to the development of a warrant or guideline for use of left turn phasing. The warrant or guideline will be developed to enable the traffic engineer to select the type of left turn phasing to be used at a particular intersection.

The stated objectives of the research project were twofold.

1. The first was to develop a research work plan to conduct a statistically valid study for the development of numerical warrants for left turn movements. The warrants, based on operational efficiency and safety, shall address the following situations: installation of new phasing, evaluation and modification of existing left turn signal phasing, and transitioning from one mode of operation to another.
2. The second objective is to review available ADOT data on signalized intersections, prepare a database of available information, and select the intersections to be used in the future study. The work plan shall address the following left turn phasing movements: permissive; leading exclusive; leading exclusive/permissive; lagging exclusive; lagging exclusive/permissive; and left turn denial.

   Note: For consistency with the previous research project on Left Turn Signal Warrants, this report uses the terms "exclusive" and "permissive" rather than the terms "protected" and "permitted." Definitions of types of left turn phasing are presented in Appendix A.

The four principal products developed by this project are:

1. A database of signalized intersections in Arizona.
2. Results of a validation study of the TEXAS computer simulation model.
3. Findings on left turn accident rates for different types of left turn phasing (using a nonrandom sample).

4. A research work plan for a future research project which will lead to the development of a warrant or guideline for use of left turn phasing.

To familiarize the reader with the scope of work and tasks conducted in this project, the study tasks are listed below. The task titles and descriptions have been taken from the request for proposals, the contract, and change order and, in some cases, have been paraphrased for clarity. The tasks are numbered as they are in the contract and in the change order. They are not presented in numerical order; rather they are presented in the logical sequence in which the tasks were performed to complete the work.

1. *Develop Microcomputer Database of Signalized Intersections*

Review available ADOT signalized intersection data and develop a microcomputer data base, using D BASE III, which identifies available information for each signalized intersection. ADOT will provide available intersection data for consultant use. The type of data used and output format shall be approved by ADOT prior to implementation.

1.A *Expand Microcomputer Database of Signalized Intersections*

Expand microcomputer database of signalized intersections to include local jurisdictions.

9. *Validate TEXAS Model*

Validate or calibrate the TEXAS Model to determine whether it reflects real world operation for left turn phasing and whether the model can be used as a tool to evaluate the operational effects of various types of left turn phasing.

10. *Workshop on TEXAS Model*

Present a workshop on design of the model, its capabilities and how it can be used. Present a live demonstration of the software.

3. *Determine Analytical Process for Evaluating Intersection Operations*

Establish the analytical process to be used in evaluating the measures of effectiveness of operations at intersections. The analytical process may utilize simulation techniques or appropriate analytical models that provide measures of operational effectiveness given variations in left turn phasing.

4.A *Develop Accident Statistics*

Develop accident statistics from a nonrandom sample of existing ADOT signalized intersections. Expand the accident statistics by including information from local jurisdictions. Stratify the statistics as functions of left turn volume and opposing volume.

4.B *Collect Accident Data on Conversions*

Collect before and after accident data from locations where the type of left turn phasing has changed.

4.C *Determine Design Approach for Safety Evaluation*

Determine the approach to be used to study the traffic accident history at selected intersections to evaluate the safety of left turn phasing alternatives. Establish the time period for the before and after sample.

2. *Prepare work plan for Future Research Project*

Prepare a work plan to conduct a statistical valid study for the development, evaluation, and application of numerical warrants for left turn movements. The matrix of experimental intersections shall include two and three through-lane intersections with permissive, leading exclusive, leading exclusive/permissive, lagging exclusive, lagging exclusive/permissive and left turn denial. The sample size of selected intersections for each of the above left turn phasing types will be determined.

5. 5.A *Prepare Interim Report*

5.B *Interim Report Review*

Prepare an interim report describing the findings and recommendations from Tasks 1, 2, 3, and 4.

6. *Select Signalized Intersections for Future Research Project*

Select the ADOT signalized intersections which fulfill the requirements of Tasks 2, 3, and 4c above. From the selected intersections, designate the preferred intersections for utilization in the experimental matrix described in Task 2. If insufficient intersections are available within the ADOT system, evaluate and specify off-system intersections which fulfill the requirements.

7. *Determine Data Collection Needs and Costs for Future Research Project*

   Determine the data collection needs and approximate costs for each of the preferred intersections to be utilized in the future study. The data collection needs and costs shall address the before and after study needs.

8. *Prepare Final Report*

   Prepare a final report documenting the analysis and findings of the study. The final report will describe the recommended work plan for the future study, the intersections selected for the study, and the approximate cost and time required for the future study. A floppy disk(s) containing the D BASE III data files will be provided to ADOT.

The final report is organized as follows.

Chapter 2 - Description of the microcomputer database of signalized intersections on the ADOT roadway network. Descriptions of the additional database of signalized intersections in local jurisdictions and the database on intersections that have been converted from one type of left turn phasing to another.

Chapter 3 - Description of the recommended design for comparing the relative safety of different types of left turn phasing.

Chapter 4 - Description of the validation testing of the TEXAS model and the study results.

Chapter 5 - Discussion of approaches for evaluating the operating characteristics of different types of left turn phasing.

Chapter 6 - Description of the criteria and approach to be used in selecting the "best" type of left turn phasing.

Chapter 7 - A proposed work plan for the future research project.

Chapter 8 - Recommendations for Further Study

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CHAPTER 2 - MICROCOMPUTER DATABASE

INTRODUCTION

Two microcomputer databases were developed in Tasks 1 and 1A of this project. The first database included each of the 496 signalized intersections in the ADOT roadway system. The second included 91 signalized intersections in 6 local jurisdictions. The microcomputer databases were created as a part of this project for four reasons.

1. The databases were useful in subsequent tasks of the project which planned the future research project. The availability of the databases allowed a determination of the completeness and suitability of the signalized intersection data for use in meeting the overall objectives of this research project and in developing the work plan for the future research project.
2. The databases were used to select those signalized intersections which will be evaluated in the future research project. All pertinent intersection data for ADOT intersections are now located in one database; that is tremendous advantage over the many diverse sources and locations of data which previously were used.
3. The databases will be useful in conducting the future research project.
4. The ADOT database will also be available to ADOT as a data source for other activities that require detailed information on specific intersections.

ADOT DATABASE

The ADOT database was compiled using dBASE III software and it is suitable for use on IBM and IBM compatible microcomputers. A copy of the database, both on hard copy and on floppy disks, has been provided to ADOT.

The database is organized in two files. The first file, named LTSG, includes identifier information, signal phasing data and geometry data. The second file, named LTTV, includes the identifier information for each intersection (this is a duplication of what appears in the LTSG file), volume data and accident data. Two files were necessary because the dBASE III program can only accommodate 128 fields in a file. A total of 163 unique fields of data are included in the two files.

There is capacity to add more fields to each file in the future if ADOT should choose to expand the database to meet additional needs or to add additional information to existing fields. Each intersection is uniquely identified by its record number. The record number for each intersection is the same in the two files.

There are 424 signalized "locations" on the ADOT roadway system. Seventy-two of these locations involve the interchange of a freeway with an arterial street (typically a diamond interchange). In these cases there are usually two actual signalized intersections, one on each side of the freeway, and each having its own volume and geometric data. For this reason "locations" of this type appear as two different records in the database files. These locations are easily distinguished in the database by the suffix "A" or "B" at the end of the intersection CODE NUMBER. For example, RECORD 1 (CODE NUMBER 20A) presents data for the north side of the diamond interchange at I-10 and Litchfield Road. RECORD 2 (CODE NUMBER 20B) presents data for the south side of the same interchange. Both files include a field called SIDE which denotes which side of the interchange (cardinal direction) is represented by the record.

The database user is cautioned about the accident data for 1983 to 1985 which is included in the "A" and "B" intersections. A breakdown of this data by side of the interchange was not available. Therefore, the accident data shown for side "A" is the total number of accidents for both sides of the interchange. The same is true of side "B". An asterisk is used to highlight the unusual treatment of the accident data.

Table 1 is an itemized list of all the elements of data which are included in the database. The left hand column lists each field exactly as it is labeled in the database. The middle column gives a verbal description of the data in each field. The right hand column notes which source of data was used to obtain each item of information (see below).

Table 2 presents a sample printout of the database for one record (a single intersection).

The data which are include in the database were provided from a variety of sources. Table B-1 in Appendix B lists the various sources of data as provided by ADOT. Different Divisions and Sections within ADOT each have an interest in different types of intersection data and compile

TABLE 1

ITEMIZED LIST OF DATA ELEMENTS INCLUDED IN DATABASE

FIELD NAME	DESCRIPTION	PRIMARY SOURCE OF DATA[1]
IDENTIFICATION DATA (identification data is presented in both the LTTV file and the LTSG file)		
RECORD_NO	RECORD NUMBER IN FILE	------------
DISTRICT	ADOT DISTRICT IN WHICH INTERSECTION IS LOCATED (1,2,3, OR 4)	1
CODE_NUM	CODE NUMBER GIVEN TO INTERSECTION BY ADOT	1
MAIN_ROUTE	MAIN ROUTE IDENTIFICATION (ROUTE NUMBER)	1
M_R_ORIENT	DIRECTIONAL ORIENTATION OF MAIN ROUTE (NS (NORTH-SOUTH) OR EW (EAST WEST))	map, 14
CROSS_STR	NAME OF STREET INTERSECTING THE MAIN ROUTE	1
MPOST_M_R	MILE POST LOCATION ON THE MAIN ROUTE	1
SIDE	FOR INTERCHANGE LOCATIONS. THIS DENOTES ON WHICH SIDE (NORTH (N), SOUTH (S) EAST (E), OR WEST (W)) OF THE INTERCHANGE THE INTERSECTION IS LOCATED	map
LOCATION	CITY OR COUNTY IN WHICH INTERSECITON IS LOCATED	1
JURISDICTN	CITY OR COUNTY WITH MAINTENANCE RESPONSIBILITY FOR THE TRAFFIC SIGNAL	1

SIGNAL PHASING AND GEOMERTY DATA (This data is presented in the LTSG file).

NOTES: Most of the data on signal phasing and geometry is presented for each approach to the intersection.

N APP or N A stands for North approach to the intersection (southbound traffic).
S APP or S A stands for South approach to the intersection (northbound traffic).
E APP or E A stands for East approach to the intersection (westbound traffic).
W APP or W A stands for West approach to the intersection (eastbound traffic).

An asterisk (*) indicates that the data is not applicable (due to only 3 legs to the intersection, one-way street, or other reasons).

TABLE 1 (Cont'd)
ITEMIZED LIST OF DATA ELEMENTS INCLUDED IN DATABASE

FIELD NAME	DESCRIPTION	PRIMARY SOURCE OF DATA[1]
LTPH	TYPE OF LEFT TURN PHASING 1. Stands for prohibited 2. Stands for exclusive 3. Stands for exclusive/permissive 4. Stands for permissive	7,8,9,10,12
LTTA	IS LEFT TURN TRAFFIC ACTUATED? F stands for False or No T stands for True or Yes	7,8,12
LELA	IS LEFT TURN LEADING OR LAGGING? 1. stands for Leading Left Turn 2. stands for Lagging Left Turn	10,12
DINT	DATE ON WHICH THE TYPE OF LEFT TURN PHASING WAS CHANGED	10
SPDL	POSTED SPEED LIMIT	13
ELTL	IS THERE AN EXCLUSIVE LEFT TURN LANE? F stand for False or No T stands for True or Yes	12
LLTL	LENGTH OF LEFT TURN LANE (FEET)	12
AWLI	APPROACH WIDTH (FEET), INCLUDING LEFT TURN LANE	12
AWLO	APPROACH WIDTH (FEET), OF LEFT TURN LANE ONLY	12
NOOL	NUMBER OF OPPOSING LANES, CONSISTS OF ALL LANES (RIGHT TURN, THROUGH, AND LEFT TURN) ON THE OPPOSITE APPROACH (EXCEPTION: WHEN AN EXCLUSIVE RIGHT TURN LANE IS PHYSICALLY SEPARATED BY AN ISLAND IT IS NOT COUNTED AS AN OPPOSING LANE) NOTE: NOOL_N_APP STANDS FOR THE NUMBER OF LANES N THE SOUTHBOUND DIRECTION	12
D OF GEO D	DATE OF THE INTERSECTION LAYOUT OR SKETCH FROM WHICH GEOMETRIC DATA WAS TAKEN	12

TABLE 1 (Cont'd)
ITEMIZED LIST OF DATA ELEMENTS INCLUDED IN DATABASE

FIELD NAME	DESCRIPTION	PRIMARY SOURCE OF DATA[1]

VOLUME DATA (This data is presented in the LTTV file)

Notes: Most of the data on volume is presented for each approach to the intersection.

N LEG, N L, N APP, or N A stands for North Leg or North Approach (southbound traffic)
S LEG, S L, S APP, or S A stands for South Leg or South Approach (northbound traffic)
E LEG, E L, E APP, or E A stands for East Leg or East Approach (westbound traffic)
W LEG, W L, W APP, or W A stands for West Leg or West Approach (eastbound traffic)

For many intersection traffic volume data were availabe from counts taken on more than one date. If data were available for more than one date, the count from the earlier data was called the "early" count and the count from the later date was called the "late" count. The dates on which the counts were taken are listed in the database.

E DATE or E stands for date of "early" traffic count
L DATE or L stands for date of "late" traffic count

An entry of NA, meaning Not Applicable, appears in a field when a turning movement does not exist due to a one-way street, or turn prohibition, or because the intersection is a "Tee."

An entry of N DATA, meaning NO DATA, appears in a field when there are not data for that turning movement.

If traffic volume data was available for only one count date the data is shown as an "early" traffic count.

TABLE 1 (Cont'd)
ITEMIZED LIST OF DATA ELEMENTS INCLUDED IN DATABASE

FIELD NAME	DESCRIPTION	PRIMARY SOURCE OF DATA[1]
EADT	AVERAGE DAILY TRAFFIC COUNT FROM THE "EARLY" DATE (VEHICLES PER DAY IN TWO DIRECTIONS)	14
LADT	AVERAGE DAILY TRAFFIC COUNT FROM THE "LATE" DATE (VEHICLES PER DAY IN TWO DIRECTIONS)	14
EVOL	APPROACH VOLUME COUNT FROM THE "EARLY" DATE (VEHICLES PER DAY IN ONE DIRECTION (APPROACHING THE INTERSECTION))	14
LVOL	APPROACH VOLUME COUNT FROM THE "LATE" DATE (VEHICLES PER DAY IN ONE DIRECTION (APPROACHING THE INTERSECTION))	14
8HTML	8-HOUR TURNING MOVEMENT COUNT (AN HOURLY AVERAGE FOR THE 8 HIGHEST HOURS), LEFT TURN	14
8HTMT	8-HOUR TURNING MOVEMENT COUNT (AN HOURLY AVERAGE FOR THE 8 HIGHEST HOURS), THROUGH	14
8HTMR	8-HOUR TURNING MOVEMENT COUNT (AN HOURLY AVERAGE FOR THE 8 HIGHEST HOURS), RIGHT TURN	14

Note: Peak hour turning movement counts are presented for both the AM peak (designated by A) and the PM peak (designated by P)

PHTML	PEAK HOUR TURNING MOVEMENT COUNT, LEFT TURN, IN VEHICLES PER HOUR	14
PHTMT	PEAK HOUR TURNING MOVEMENT COUNT, THROUGH, IN VEHICLES PER HOUR	14
PHTMR	PEAK HOUR TURNING MOVEMENT COUNT, RIGHT TURN, IN VEHICLES PER HOUR	14

ACCIDENT DATA (This data is presented in the LTTV File)

Note: Data on NO LTA (number of "Left Turn" Accidents) and NO A I (Number of Angle Accidents) are given by year (82,83,84) and by a three year total (TOT)

NO_LTA	NUMBER OF "LEFT TURN" ACCIDENTS	2,3,4,5
NO_A_I	NUMBER OF "ANGLE" ACCIDENTS	2,3,4,5

Note: Caution should be used when accident data at interchange locations (these locations have an asterisk in this data field). See discussion in Chapter 2

TABLE 1 (Cont'd)
ITEMIZED LIST OF DATA ELEMENTS INCLUDED IN DATABASE

FIELD NAME	DESCRIPTION	PRIMARY SOURCE OF DATA[1]
NOLTA 8385	NUMBER OF "LEFT TURN" ACCIDENTS FOR A THREE YEAR PERIOD (1/1/83 THROUGH 12/31/85)	6
NOANG 8385	NUMBER OF "ANGLE" ACCIDENTS FOR A THREE YEAR PERIOD (1/1/83 THROUGH 12/31/85)	6
NOACC 8385	NUMBER OF "TOTAL" ACCIDENTS FOR A THREE YEAR PERIOD (1/1/83 THROUGH 12/31/85)	6
MISCELLANEOUS DATA AND INFORMATION:		
PED_VOL	PEDESTRIAN VOLUME CROSSING THE LEG OF THE INTERSECTION INDICATED	14
PV_DATE	DATE OF PEDESTRIAN VOLUME COUNT	14
S_LAND_USE	SURROUNDING LAND USE	-------------
COMM_FIELD	COMMENT FIELD	-------------

[1]Source numbers refer to the sources listed in Table B-1

TABLE 2
SAMPLE PRINTOUT OF THE ADOT DATABASE

LTSG File

FIELD NAME	DATA	FIELD NAME	DATA
DISTRICT	1	SPDL_S_APP	
CODE_NUM	20A	SPDL_N_APP	
MAIN_ROUTE	I-10	SPDL_W_APP	55
M_R_ORIENT	EW	SPDL_E_APP	55
CROSS_STR	LITCHFIELD	ELTL_S_APP	T
MPOST_M_R	128.69	ELTL_N_APP	F
SIDE	N	ELTL_W_APP	F
LOCATION	MRCPA CO	ELTL_E_APP	T
JURISDICTN	ADOT	ELTL_E_APP	T
LTPH_S_APP	3	LLTL_S_APP	360
LTPH_N_APP	1	LLTL_N_APP	*
LTPH_W_APP	*	LLTL_W_APP	*
LTPH_E_APP	4	LLTL_E_APP	210
LTTA_S_APP	T	AWLI_S_APP	36
LTTA_N_APP	F	AWLI_N_APP	*
LTTA_W_APP	F	AWLI_W_APP	*
LTTA_E_APP	T	AWLI_E_APP	24
LTTA_E_APP	T	AWLO_S_APP	12
LELA_S_APP	2	AWLO_N_APP	*
LELA_N_APP	*	AWLO_W_APP	*
LELA_W_APP	*	AWLO_E_APP	26
LELA_E_APP	*	NOOL_S_APP	4
DINT_S_APP		NOOL_N_APP	*
DINT_N_APP		NOOL_W_APP	*
DINT_W_APP		NOOL_E_APP	*
DINT_E_APP		NOOL_E_APP	*
		D_OF_GEO_D	12/01/78

LTTV File

DISTRICT	1	S_L_L_DATE	03/18/81
CODE_NUM	**20A	E_LEG_EADT	244
MAIN_ROUTE	I-10	E_L_E_DATE	03/16/81
M_R_ORIENT	EW	E_L_L_ADT	
CROSS_STR	LITCHFIELD	E_L_L_DATE	03/18/81
MPOST_M_R	128.69	W_LEG_EADT	430
SIDE	N	W_L_E_DATE	03/16/81
LOCATION	MRCPA CO	W_L_L_ADT	
JURISDICTN	ADOT	W_L_L_DATE	03/18/81
N_LEG_EADT	9087	N_APP_EVOL	4566
N_L_E_DATE	03/16/81	N_A_E_DATE	03/16/81
N_L_L_ADT		N_A_L_VOL	
N_L_L_DATE	03/18/81	N_A_L_DATE	03/18/81
S_LEG_EADT	9199	S_APP_EVOL	4820
S_L_E_DATE	03/16/81	S_A_E_DATE	03/16/81
S_L_L_ADT		S_A_L_VOL	
S_L_L_DATE	03/18/81	S_A_L_DATE	03/18/81
S_A_L_DATE	03/18/81	NA_DATE_PM	03/16/81
E_APP_EVOL	244	SA_PHTML_A	28
E_A_E_DATE	03/16/81	SA_PHTMT_A	257

TABLE 2 (Cont'd)
SAMPLE PRINTOUT OF THE ADOT DATABASE

LTTV File

FIELD NAME	DATA	FIELD NAME	DATA
E_A_L_VOL		SA_PHTMR_A	NA
E_A_L_DATE	/ /	SA_DATE_AM	03/16/81
W_APP_EVOL	NA	SA_PHTML_P	41
W_A_E_DATE	03/16/81	SA_PHTMT_P	757
W_A_L_VOL		SA_PHTMR_P	NA
W_A_L_DATE	03/18/81	SA_DATE_PM	03/16/81
NA_8HTML_E	NA	EA_PHTML_A	40
NA_8HTMT_E	329	EA_PHTMT_A	1
NA_8HTMR_E	16	EA_PHTMR_A	16
NA_E_DATE	03/16/81	EA_DATE_AM	03/16/81
NA_8HTML_L		EA_PHTML_P	2
NA_8HTMT_L		EA_PHTMT_P	0
NA_8HTMR_L		EA_PHTMR_P	4
NA_L_DATE	03/18/81	EA_DATE_PM	03/16/81
NA_L_DATE	03/18/81	EA_DATE_PM	03/16/81
SA_8HTML_E	29	WA_PHTML_A	NA
SA_8HTMT_E	344	WA_PHTMT_A	NA
SA_8HTMR_E	NA	WA_PHTMR_A	NA
SA_E_DATE	03/16/81	WA_DATE_AM	03/16/81
SA_8HTML_L		WA_PHTML_P	NA
SA_8HTMT_L		WA_PHTMT_P	NA
SA_8HTMR_L		WA_PHTMR_P	NA
SA_L_DATE	03/18/81	WA_DATE_PM	03/18/81
EA_8HTML_E	11	NO_LTA_82	
EA_8HTMT_E	0	NO_LTA_83	
EA_8HTMR_E	6	NO_LTA_84	
EA_E_DATE	03/16/81	NO_LTA_TOT	
EA_8HTML_L		NO_A_I_82	
EA_8HTMT_L		NO_A_I_83	
EA_8HTMR_L		NO_A_I_84	
EA_L_DATE	/ /	NO_A_I_TOT	
EA_L_DATE	/ /	NO_A_I_TOT	
WA_8HTML_E	NA	NOLTA_8385	*0
WA_8HTMT_E	NA	NOANG_8385	*1
WA_8HTMR_E	NA	NOACC_8385	*3
WA_E_DATE	03/16/81	PED_VOL_NL	0
WA_8HTML_L		PV_DATE_NL	03/18/81
WA_8HTMT_L		PED_VOL_SL	0
WA_8HTMR_L		PV_DATE_SL	03/18/81
WA_L_DATE	03/18/81	PED_VOL_EL	0
NA_PHTML_A	NA	PV_DATE_EL	03/18/81
NA_PHTMT_A	632	PED_VOL_WL	0
NA_PHTMR_A	10	PV_DATE_WL	03/18/81
NA_DATE_AM	03/16/81	S_LAND_USE	
NA_PHTML_P	NA	COMM_FIELD	
NA_PHTMT_P	366		
NA_PHTMR_P	16		
NA_DATE_PM	03/16/81		

their own individual databases. The value of a single comprehensive signalized intersection database which can be used throughout ADOT is evident.

Several observations were made by the research team while working with the base data provided by ADOT and in compiling the database. It is worthwhile to make note of these observations and pass them on to users of the microcomputer database.

1. Data were acquired from many different sources and documents (see Table B-1). Different sources used different methods of identifying intersections. For example, different data sources identify U.S. 60 as Main Street, U.S. 60, or the Apache Trail (in Mesa), or as Apache Boulevard, etc. (in Tempe). Use of different names caused some confusion, particularly for data in parts of the state with which the research team is not completely familiar. In the microcomputer database a route number is consistently used to identify the MAIN ROUTE. The route number is often supplemented by the street name if the roadway has one.

2. For most data categories, data were not available from ADOT for every signalized intersection in the state. For type of left turn phasing, for example, over 130 intersections did not have data available. Available information was somewhat sketchy and, in many cases, had to be pulled together in a logical sense. While one data source provided the width of the approach for the main route, it was not given for the cross street. On at least one occasion the same milepost was listed for two different intersections.

3. The reduced blueprints (intersection layout sheets) of intersections were difficult to work with. The scale of the drawings had to be estimated in most cases. Some intersection had more than one layout sheet, each showing different geometric information for the intersection. In some cases there was no clear indication as to which design had actually been constructed. Intersection layout sheets were not available for some intersections.

The reliability of the data provided to the research team is not known; the research team assumes no responsibility for the accuracy of the data supplied by ADOT. The team noted that some intersection geometric data were out of date and erroneous due to intersection geometric improvements done over the years. Significant changes in lane geometry have occurred at some intersections since the data sources in items 11 and 12 (Table B-1) were created.

Some of the data supplied and incorporated in the database was more than ten years old. Some of the geometric data and some of the signal phasing data are this old. The remainder of the data was generally less than five years old. While some of the geometric and signal phasing data may be several years old, this, in itself, does not mean that the data is no longer accurate or valid. No field checks were conducted by the research team to verify that data are current; without a field check the accuracy of the data cannot be confirmed.

There are definitely gaps in the data coverage. Table 3 shows, for each field, how many records in each file have data included in the database. For some intersections, there is virtually no useful information, and for other intersections significant data are not available. In general, geometric data is available for only about one-third of the intersections. Approach speed limits are available only for the main route and not for the cross street. The number of opposing lanes is available for only about half of the intersections. One-third of the intersections do not have data on the type of left turn phasing. In general, about one-half of the intersections do not have traffic volume data.

In addition to noting how many intersections have a particular type of data, it is of interest to note how many intersections have a good "supply" or a good "coverage" of data. After reviewing the magnitude of the gaps in the data described above it would be surprising to find a large number of intersections which have data available in most categories. This suspicion is borne out by a review of individual intersections.

An intersection which has a good "coverage" of data might be defined as one which has certain key data elements available. In terms of the future research project to develop left turn signal warrants there are seven key data elements--

TABLE 3. NUMBER OF RECORDS FOR WHICH DATA IS INCLUDED IN THE ADOT DATABASE.(LTSG File)

FIELD	RECORDS
Record No	496
DISTRICT	496
CODE_NUM	496
MAIN_ROUTE	496
M_R_ORIENT	496
CROSS_STR	496
MPOST_M_R	496
SIDE	150
LOCATION	496
JURISDICTN	496
LTPH_S_APP	302
LTPH_N_APP	302
LTPH_W_APP	316
LTPH_E_APP	313
LTTA_S_APP	496
LTTA_N_APP	496
LTTA_W_APP	496
LTTA_E_APP	496
LELA_S_APP	285
LELA_N_APP	283
LELA_W_APP	303
LELA_E_APP	299
DINT_S_APP	35
DINT_N_APP	34
DINT_W_APP	23
DINT_E_APP	9
SPDL_S_APP	214
SPDL_N_APP	214
SPDL_W_APP	236
SPDL_E_APP	236
ELTL_S_APP	496
ELTL_N_APP	496
ELTL_W_APP	496
ELTL_E_APP	496
LLTL_S_APP	173
LLTL_N_APP	168
LLTL_W_APP	175
LLTL_E_APP	178
AWLI_S_APP	205
AWLI_N_APP	199
AWLI_W_APP	200
AWLI_E_APP	205
AWNO_S_APP	178
AWLO_N_APP	174
AWLO_W_APP	195
AWLO_E_APP	190
NOOL_S_APP	236
NOOL_N_APP	234
NOOL_W_APP	238
NOOL_E_APP	243
D_OF_GEO_D	

TABLE 3 - (Cont'd)
LTTV File

FIELD	RECORDS	FIELD	RECORDS
Record No.	496	EA_8HTML_L	184
DISTRICT	496	EA_8HTMT_L	184
CODE_NUM	496	EA_8HTMR_L	184
MAIN_ROUTE	496	EA_L_DATE	
M_R_ORIENT	496	WA_8HTML_E	285
CROSS_ST	496	WA_8HTMT_E	285
MPOST_M_R	496	WA_8HTMR_E	285
SIDE	151	WA_E_DATE	
LOCATION	496	WA_8HTML_L	183
JURISDICTN	496	WA_8HTMT_L	183
N_LEG_EADT	487	WA_8HTMR_L	183
N_L_E_DATE		WA_L_DATE	292
N_L_L_ADT		NA_PHTML_A	292
N_L_L_DATE		NA_PHTMT_A	292
S_LEG_EADT	290	NA_PHTMR_A	
S_L_E_DATE		NA_DATE_AM	
S_L_L_ADT	188	NA_PHTML_P	292
S_L_L_DATE		NA_PHTMT_P	292
E_LEG_EADT	289	NA_PHTMR_P	292
E_L_E_DATE		NA_DATE_PM	
E_L_L_ADT	188	SA_PHTML_A	292
E_L_L_DATE		SA_PHTMT_A	292
W_LEG_EADT	290	SA_PHTMR_A	292
W_L_E_DATE		SA_DATE_AM	
W_L_L_ADT	188	SA_PHTML_P	292
W_L_L_DATE		SA_PHTMT_P	292
N_APP_EVOL	289	SA_PHTMR_P	292
N_A_E_DATE		SA_DATE_PM	
N_A_L_VOL	187	EA_PHTML_A	292
N_A_L_DATE		EA_PHTMT_A	292
S_APP_EVOL	290	EA_PHTMR_A	292
S_A_E_DATE		EA_DATE_AM	
S_A_L_VOL	188	EA_PHTML_P	292
S_A_L_DATE		EA_PHTMT_P	292
E_APP_EVOL	290	EA_PHTMR_P	292
E_A_E_DATE		EA_DATE_PM	
E_A_L_VOL	188	WA_PHTML-A	292
E_A_L_DATE		WA_PHTMT_A	292
W_APP_EVOL	290	WA_PHTMR_A	292
W_A_E_DATE		WA_DATE_AM	
W_A_L_VOL	188	WA_PHTML_P	292
W_A_L_DATE		WA_PHTMT_P	292
NA_8HTML_E	286	WA_PHTMR_P	292
NA_8HTMT_E	287	WA_DATE_PM	
NA_8HTMR_E	287	NO_LTA_82	162
NA_E_DATE		NO_LTA_83	162
NA_8HTML_L	185	NO_LTA_84	162
NA_8HTMT_L		NO_LTA_TOT	162
NA_8HTMR_L	185	NO_A_I_82	162
NA_L_DATE		NO_A_I_83	162

TABLE 3 - (Cont'd)
LTTV File

FIELD	RECORDS
SA_8HTML_E	286
SA_8HTMT_E	286
SA_8HTMR_E	285
SA_E_DATE	
SA_8HTML_L	184
SA_8HTMT_L	184
SA_8HTMR_L	184
SA_L_DATE	
EA_8HTML_E	286
EA_8HTMT_E	286
EA_8HTMR_E	286
EA_E_DATE	
NO_A_I_84	162
NO_A_I_TOT	162
NOLTA 8385	267
NOANG 8385	267
NOACC 8385	267
PED_VOL_NL	292
PV_DATE_NL	
PED_VOL_SL	292
PV_DATE_SL	
PED_VOL_EL	292
PV_DATE_EL	
PED_VOL_WL	292
PV_DATE_WL	
S LAND USE	0

1. type of left turn phasing,
2. information, leading versus lagging left turn,
3. posted speed limit,
4. the presence or absence of a separate left turn lane,
5. number of opposing lanes,
6. volume, and
7. accidents.

A review of individual intersections shows that fewer than 55 intersections have data in all five of the categories (1 through 5) listed above and peak hour turning moving counts. These intersections could be described as being relatively data "rich" while the remaining 440 (approximate number) intersections could be described as being relatively data "poor."

The availability of fewer than 55 intersections with a "rich" database presents a limited sample for designing a future research project. This is particularly true considering the fact that these 55 intersections are varied in terms of their characteristics. The type of phasing, speed limit, presence or absence of a separate left turn lane, number of opposing lanes and other characteristics vary from intersection to intersection. The size of subsets of intersections having like characteristics would be rather small.

Since the type of left turn phasing is a very important characteristic, it is important to note the number of intersections for each type of left turn phasing. In the entire database (496 intersections) there are only 10 intersections that have exclusive left turn phasing on all four approaches. Only 11 intersections have exclusive/permissive phasing on all four approaches. One hundred thirteen intersections have permissive phasing on all four approaches and 137 intersections have no data at all on the type of left turn phasing. The small number of intersections which have exclusive phasing on all approaches or exclusive/permissive phasing on all approaches makes design of the future research project and evaluation of relative safety more difficult. Comparison of total intersection accidents is only useful when the type of left turn phasing is the same on all four approaches. Evaluation of "left turn" and "angle" accidents when the type of phasing is different on various approaches requires much greater care in evaluating accident data.

The above review of the data indicated that data coverage, for most intersections, is incomplete. The relatively small number of intersections that currently have a good coverage of data provides a meager sample of intersections to be used in analyses of safety and/or operations. For this reason, data on signalized intersections was also collected from local jurisdictions in Arizona. The addition of local intersections expanded the number of locations available for analysis.

LOCAL JURISDICTION DATABASE

Information on local signalized intersections was solicited from the eight local jurisdictions listed below (see Appendix C for a sample letter soliciting this information). Six of the jurisdictions (identified by an asterisk) volunteered to contribute information. Shown in parentheses is the number of intersections for which a jurisdiction provided information.

	Phoenix	
*	Tempe	(20)
*	Mesa	(16)
*	Scottsdale	(51)
*	Glendale	(18)
	Tucson	
*	Maricopa County	(7)
*	Pima County	(20)
	TOTAL	(132)

The data elements requested from local jurisdictions were not as extensive as those acquired from ADOT. Selected data elements were obtained to determine the location, type of left turn phasing, geometry and turning movements. Copies of the survey forms used to obtain the data from the local jurisdictions are shown in Appendix C. Jurisdictions were asked, in addition to providing information on typical intersections, to provide information on intersection approaches that had been converted from one type of left turn phasing to another. Jurisdictions were asked to provide information for intersections that have two or three lanes of opposing traffic, exclusive left turn lanes, and have turning movement counts available.

The data from local jurisdictions was obtained primarily to enlarge the number of locations with information that could be used to calculate accident rates for various types of left turn phasing (see Chapter 3). Because complete information was provided for most of the 132 local intersections, this greatly enlarged the data set that could be used to calculate accident rates for various types of left turn phasing. Accident data for these intersections was obtained through ADOT from the ALISS accident records system.

A separate database was created for the local jurisdiction intersections. It was also compiled using dBASE III software. The database is contained entirely in one file. Each file contains 74 fields of data. Table 4 is an itemized list of all the elements of data which are included in the local jurisdiction database. The left hand column lists each field exactly as it is labeled in the database. The right hand column gives a verbal description of the data in each field. Table 5 is a sample printout of the database for one record (a single intersection).

TABLE 4
ITEMIZED LIST OF DATA ELEMENTS INCLUDED IN LOCAL INTERSECTION DATABASE

FIELD NAME	DESCRIPTION
NORTH-SOUTH	Name of north-south street
EAST-WEST	Name of east-west street
JURSIDICTN	City or county with responsibility for the traffic signal

NOTES: Most of the data on signal phasing and geometry is presented for each approach to the intersection.

N APP or N A stands for North approach to the interesection (southbound traffic).
S APP or S A stands for South approach to the intersection (northbound traffic).
E APP or E A stands for East approach to the interesection (westbround traffic).
W APP or W.A. stands for West approach to the intersection (eastbound traffic).

For many intersections the type of left turn phasing has changed. Sometimes it has changed more than once.

DINT	Date of installation of the original left turn phasing.
DINTC1	Date of the first change (if any) in type of left turn phasing.
DINTC2	Date of the second change (if any) in type of left turn phasing.

NOTES: The time period between DINT and DINTC1 is referred to as the Before (B) period.
The time period between DINTC1 and DINTC2 is referred to as the After (A) period.
The time period after DINTC2 is referred to as the After-After (AA) period.

The lending letters of A,B, or AA in a field name refer to thesc time periods.

LTPH — TYPE OF LEFT TURN PHASING
1. Stands for prohibited
2. Stands for exclusive
3. Stands for exclusive/permissive
4. Stands for permissive

LELA — IS LEFT TURN LEADING OR LAGGING?
1. Stands for Leading Left Turn
2. Stands for Lagging Left Turn

ELTL — IS THERE AN EXCLUSIVE LEFT TURN LANE?
F stands for False or No
T stands for True or Yes

NOOL — NUMBER OF OPPOSING LANES, CONSISTS OF ALL LANES (RIGHT TURN, THROUGH, AND LEFT TURN) ON THE OPPOSITE APPROACH (EXCEPTION: WHEN AN EXCLUSIVE RIGHT TURN LANE IS PHYSICALLY SEPARATED BY AN ISLAND IT IS NOT COUNTED AS AN OPPOSING LANE).

NOTE: NOOL-N-APP STANDS FOR THE NUMBER OF LANES IN THE <u>SOUTH</u>BOUND DIRECTION.

TABLE 4 (Cont'd)
ITEMIZED LIST OF DATA ELEMENTS INCLUDED IN LOCAL INTERSECTION DATABASE

CHNGINTGEO	HAS THERE BEEN ANY CHANGE IN INTERESECTION GEOMETRY SINCE 1982? F Stands for False or No T Stands for True or Yes
24HTM	TURNING MOVEMENT COUNT FOR A 24-HOUR PERIOD. The two leading letters refer to the approach. E.G. NA = north approach. The trailing letter refers to the turning movement. L = Left T = Through R = Right The single suffix letter E or L is used to differentiate between turning movement counts on two different dates. If there is only one turning movement count, it is listed as "E". If there are two turning movement counts, the earlier one is listed as "E" and the later one is listed as "L."
E24HTMDATE	The date of the earlier (or single) turning movement count.
L24HTMDATE	The date of the later turning movement count.

TABLE 5
SAMPLE PRINTOUT OF THE LOCAL INTERSECTION DATABASE

FIELD NAME	DATA	FIELD NAME	DATA
NORTH_SOUTH	GRANITE REEF	AALELA_E_A	2
EAST_WEST	McDOWELL	AALELA_W_A	2
JURSIDICTION	SCOTTSDALE	ELTL_N_APP	T
DINT_N_APP	04/27/67	ELTL_S_APP	T
DINT_S_APP	04/27/67	ELTL_E_APP	T
DINT_E_APP	11/05/86	ELTL_W_APP	T
DINT_W_APP	04/27/67	NOOL_N_APP	2
DINTC1_N_A	/ /	NOOL_S_APP	2
DINTC1_S_A	/ /	NOOL_E_APP	3
DINTC1_E_A	06/07/88	NOOL_W_APP	3
DINTC1_W_A	12/15/88	CHNGINTGEO	T
DINTC2_N_A	/ /	NA24HTML_E	1260
DINTC2_S_A	/ /	NA24HTML_E	1260
DINTC2_E_A	01/26/89	NA24HTMT_E	2218
DINTC2_W_A	01/26/89	NA24HTMR_E	1027
BLTPH_N_AP	4	SA24HTML_E	1051
BLTPH_S_AP	4	SA24HTMT_E	4136
BLTPH_S_AP	4	SA24HTMR_E	995
BLTPH_E_AP	2	EA24HTML_E	1087
BLTPH_W_AP	4	EA24HTMT_E	10624
BLELA_N_AP		EA24HTMR_E	2561
BLELA_S_AP		WA24HTML_E	1396
BLELA_E_AP	1	WA24HTMT_E	8323
BLELA_W_AP		WA24HTMR_E	769
ALTPH_N_AP	4	E24HTMDATE	06/04/87
ALTPH_S_AP	4	NA24HTML_L	0
ALTPH_E_AP	3	NA24HTMT_L	0
ALTPH_W_AP	3	NA24HTMR_L	0
ALELA_N_AP		SA24HTML_L	0
ALELA_S_AP		SA24HTML_L	0
ALELA_E_AP	1	SA24HTMT_L	0
ALELA_W_AP	1	SA24HTMR_L	0
AALTPH_N_A	4	EA24HTML_L	0
AALTPH_S_A	4	EA24HTMT_L	0
AALTPH_S_A	4	EA24HTMR_L	0
AALTPH_E_A	3	WA24HTML_L	0
AALTPH_W_A	3	WA24HTMT_L	0
AALELA_N_A		WA24HTMR_L	0
AALELA_S_A		L24HTMDATE	/ /

CHAPTER 3 - RECOMMENDED DESIGN FOR COMPARING THE RELATIVE SAFETY OF DIFFERENT TYPES OF LEFT TURN PHASING

INTRODUCTION

The objective of the safety evaluation is to detect differences (if any) in accident experience for the three different types of left turn phasing and, if possible, for leading versus lagging operation as well. The Request for Proposals stated that the approach used to detect differences in accident experience must provide statistically sound results. In addition, it is desirable to select an approach which has data requirements that are compatible with the data already available in the microcomputer databases and/or which can be reasonably acquired through data collection.

The most common method of comparing accident experience at intersections is the accident rate method. The basic data required for this method are the number of accidents and traffic volume information for a given period of time. The left turn accident is the most appropriate accident type, in the opinion of the research team, for evaluating accident experience for left turn phasing. In addition to stratifying intersections by type of left turn phasing, stratification by number of opposing lanes, left turn volume and opposing volume may reveal more about relative accident experience.

This chapter will:

- Discuss different candidate approaches or designs that can be used for conducting a safety evaluation and discuss the advantages and disadvantages of each.
- Present information on accident statistics for intersections in the ADOT and local jurisdiction databases.
- Present information on before and after accident statistics for intersection approaches that have been converted from one type of left turn phasing to another.
- Recommend a design to be used for the safety evaluation to be conducted in the future research project.

One of the responsibilities of this project was to recommend a design for comparing the relative safety of different types of left turn phasing in the future research project. The study team evaluated several different candidate designs that could be used for conducting a safety evaluation. This section will discuss those various designs and their advantages and disadvantages.

COMMONLY USED DESIGNS TO EVALUATE A SINGLE TREATMENT

Several different candidate approaches or designs are available for conducting a safety evaluation. Those designs that are commonly used in safety evaluations to evaluate a *single treatment* are identified as follows:

1. Simple Comparison
2. Simple before/after design
3. Before/after design with randomized control group
4. Before/after design with comparison group
5. Before/after design with a comparison group, and a check for comparability
6. Interrupted time series design
7. Time series with comparison groups
8. Time series with comparison variables, and
9. Time series with switching variables.

Each design has its own unique assumptions and stipulations which must be satisfied in order to insure that relevant statistical results are obtained. The first three of the above designs were considered by the research team and are described on the following pages.

Each design has its own advantages and disadvantages for use in safety evaluations. Selection of a design must be exercised carefully to avoid pitfalls in the analysis. For example, a simple before/after design is vulnerable to several threats to its validity including "History," "Maturation," "Regression to the Mean," and "Instability." These threats are fully described on pages 38-41 of FHWA's *Accident Research Manual* (1). Lindsay Griffin's paper entitled "Three Procedures for Evaluating Highway Safety Improvement Programs" (3) also describes threats to validity. Both documents present good descriptions of the more commonly used designs for safety evaluations and for that reason the designs are not extensively described here.

A significant amount of historical data is available. Historical data for left turn accidents will be presented and discussed later in this chapter. Because historical data is available, it is important to consider the possible use of historical data alone. Potentially, there are two different ways in which historical accident data could be used to conduct a safety evaluation. However, each of these ways has shortcomings which the reader should understand. The two ways of using historical data are described below.

SIMPLE COMPARISON OF ACCIDENT RATES

The first way in which historical data could be used is to assign signalized intersections (or approaches) to one of five groups and then compare the accident rate for each group. The five groups would be: Group A -- intersections (approaches) with permissive left turn phasing; Group B--intersections (approaches) with leading exclusive/permissive left turn phasing; Group C -- intersections (approaches) with lagging exclusive/permissive left turn phasing; Group -- D intersections (approaches) with leading exclusive phasing; and Group E -- intersections with lagging exclusive phasing. This is a basic approach that will be used to present accident statistics later in this chapter. If a common time period is used for evaluating accidents for each of these groups then three of the more common "threats to validity" (see pages 39-41 of the FHWA *Accident Research Manual*) can be overcome. These three threats are History, Maturation, and Regression Artifacts.

If **all** intersections (approaches) with permissive left turn phasing are assigned to Group A, and all intersections (approaches) with leading exclusive/permissive left turn phasing are assigned to Group B, and so forth, then a different type of error will be introduced. That error is that each group would have different intersection characteristics. The most obvious difference--one which will be confirmed by data presented later in this chapter -- is that some groups have much different traffic volumes than others. If comparisons were to be made of the accident rates experienced by Groups A, B, C,D and E, it could not conclusively be stated that differences in accident rates were due to different types of left turn phasing. It is, in fact, quite possible that some or all of the differences in accident rates could be attributed to differences in traffic volume or other intersection characteristics. Tables 7 and 8, discussed later in this chapter, illustrate how misleading it can be to simply use groups as described above. Those tables show that left turn accident rate is influenced by left turn volume and opposing volume. Using a random sample from the ADOT and local jurisdiction signalized intersections to create Groups A-E would not overcome this problem.

If intersections are not selected at random, but rather are selected so that intersection characteristics are similar in all groups, then the chance of error is reduced, but not eliminated. Stratification by volume, as is done in Tables 7 and 8, for example, is one way of doing this.

To summarize, the advantages and disadvantages of this approach, using data already compiled, are shown below.

Advantages

A. The data are currently available.

B. Most of the data are based on a common time period at all locations; hence, there is a reduced concern about history, maturation and regression artifacts threats to validity affecting the conclusions.

Disadvantages

A. A primary disadvantage of this option is that the statistical design is weaker than other options. This option would preclude the setting up of a statistical design in which Type I and Type II errors are of paramount importance. Furthermore, it is a weaker statistical design in that intersections were not randomly assigned for treatment (conversion to a different type of left turn phasing). A particular intersection approach falls into a particular group because there was a perceived or demonstrated need to have that type of left turn phasing on that approach. This introduces a bias because all locations do not have an equal chance of being treated with a certain type of left turn phasing. For example, some types of left turn phasing may tend to have higher volumes than others.

B. Another concern in this option is the reduced confidence of historical turning movement counts utilized to calculate accident rates.

C. In certain cases, such as lagging exclusive phasing there is an unacceptably small sample size of empirical data for left turn accident rates.

SIMPLE BEFORE/AFTER DESIGN

The second way in which historical data could be used is to evaluate "before" and "after" accident data for those locations where the type of left turn phasing was changed in the past or will be changed in the near future. This design can include both those conversions which have been or will be made by ADOT and those conversions that have been or will be made by local jurisdictions. Data provided by ADOT (Source 10 in Table B-1) lists 61 intersections which were changed from permissive phasing and which have "before" and "after" accident data available. The dates on which the left turn phasing was changed at these intersections ranges from as early as 1955 to as late as 1985. Since there are a variety of dates, this approach would be subject to threats to validity due to History, Maturation, and Regression Artifacts if all of these intersections were used.

Additional data on conversions, from local jurisdictions, is also available. The additional data increases the sample size but, again the conversions were made on a variety of dates throughout the 1980's. The variation in dates has an effect on the quality of the statistics. To summarize, the advantages and disadvantages of this approach, are shown below.

Advantages

A. Does not require conversion of left turn phasing (other than those which jurisdictions have implemented or will implement anyway)

Disadvantages

A. The design has an inherent bias in that intersections are not randomly assigned for conversion or to a control group. This makes the conclusions somewhat suspect since all locations do not have the same chance of being treated, i.e., converted from one type of left turn phasing to another. The treatment group is treated (changed from one type of left turn phasing to another) because of a demonstrated need rather than being treated on a random basis. This lack of random assignment of traffic intersections has a major impact on the relative strength of this design.

B. This approach requires a minimum sample size so that sound statistics for mean accident rate and the standard deviation can be developed. It should be noted that approximately 40 or fewer intersection approaches in the ADOT signalized intersection database have been changed from one type of phasing to another since 1979. There are not enough locations in the ADOT database alone to design a safety evaluation of this type. A database would have to be augmented with information from converted locations in local jurisdictions as will be done with historical conversion data later in this chapter.

C. An additional concern on the part of the research team is the conversion of traffic signals at different points in time at different intersections. This consideration is relevant since the impacts of history, maturation and regression artifacts may be present and difficult to overcome. Similarly, it is more difficult to establish a control group or a comparison group when conversions have taken place during various years.

D. Lower confidence in the historical turning movement count data.

E. While some types of conversions may be made from time to time, other types of conversions may never be made. Conversions that are not made do not provide a comparison.

BEFORE/AFTER DESIGN WITH RANDOMIZED CONTROL GROUP

This type of experimental design enables the researcher to compare the accident rate of a control group with the accident rate of another group that has been "treated" in a prescribed manner. This treatment could be the installation of exclusive left turn phasing or some other type of left turn phasing different from the control group.

Successful use of the before/after design with randomized control group would be predicated upon successfully accomplishing a series of steps. These steps are as follows:

(a) identify a set of intersections with permissive left turn phasing;

(b) convert one-half to exclusive left turn phasing (this would constitute a "treatment" for conducting the statistical study);

(c) collect accident data over a period of time; and

(d) compare accident rate experience between the two groups.

The following paragraphs describe each of the above steps in the study design in more detail.

1. A set of intersections currently having permissive left turn phasing would be selected. The intersections would have relatively high traffic volumes (high enough such that they would be approaching the conditions where exclusive phasing might be considered). The intersections would also be selected so that the group would be reasonably homogeneous in terms of intersection characteristics such as adequate sight distance and approach speed. The nature of the intersection characteristics for the set of intersections should be typical of signalized intersections in Arizona. It is possible that two (or maybe more) sets of intersections might be created and that each set of intersections might be evaluated separately in succeeding steps. For example, there might be separate sets for intersections with two opposing lanes and with three opposing lanes.

2. Each of the intersections would be randomly assigned the type of treatment it would receive during the evaluation period. Random assignment can be assured by using a random number generator type of process. One-half of the intersections would be assigned the treatment of exclusive left-turn phasing and other half would serve as the control group (no treatment).

3. "Before" accident data would be obtained for each intersection. Data would be collated by group (treatment group and control group). A "before" accident period of 2 to 3 years is recommended; this duration must be consistent at all intersections where data is collected. Historical data for the most recent 2 to 3 years may, and from a practical standpoint, should be used.

4. The treatment would be installed at each designated intersection location (one-half of the intersections). Note: It is not essential that the treatment be installed on all four approaches to an intersection.

5. "After" accident data would be accumulated at each location. To reduce threats to validity, data should be collected for a common time period for each location. A "break-in" period of one to three months after installation should be employed to allow drivers to become accustomed to the new phasing. The research team believes that at least two years of accident data will be needed to develop statistically meaningful results on the accident rate of the different groups.

6. Accident data would be statistically evaluated using the before/after design with randomized control group to detect the relative difference in accident rate experience for the two types of left turn phasing.

To summarize, the advantages and disadvantages of this approach are shown below.

Advantages

A. It is statistically rigorous, enabling meaningful conclusions to be drawn from empirical data. It is based upon the random assignment of traffic intersections to either a control group or a study group.

B. This design effectively overcomes the threats to validity caused by history (other causes at the same time), maturation (trends over time) and regression artifacts.

C. Another strong point of this design is the high confidence in the accuracy of the turning movement counts used to develop accident rates.

Disadvantages

A. Requires an impractically large number of field conversion locations which must be implemented if this design is selected.

EVALUATION OF MULTIPLE TREATMENTS

The three candidate approaches or designs described up to this point are those which can be used to evaluate a *single* treatment. These designs do not enable the researcher to compare accident rates of two or more treatments (multiple treatments). They could be used to compare a treatment (leading exclusive left turn phasing) to a control group (permissive left turn phasing). These designs *could not*, however, be used to compare two different treatments (leading exclusive phasing and leading exclusive/permissive phasing) to a control group (permissive phasing) or to one another.

It is highly desirable that the planned research study recommend an experimental design which has the capability to compare different treatments to one another as well as to a control group. At a minimum, it would be desirable to compare permissive left turn phasing, exclusive left turn phasing, and exclusive/permissive left turn phasing to one another. Beyond this, it is of interest to consider any differences in accident experience due to leading and lagging operation. An approach or design which enables this to be done is embodied in a statistical method called Analysis of Variance.

There are, however,practical problems involving implementation as well as inherent assumptions which must be made in order to use this particular experimental design. In order for the results of this study to be statistically sound, the Analysis of Variance experimental design requires that equal variances in accident rate be observed for each type of left turn phasing considered. This requirement may not be satisfied (based upon preliminary statistical analyses of the empirical data obtained during this study). In addition, the required sample size which would satisfy acceptable sampling risks to ADOT would require more intersections than are available in the ADOT and local jurisdiction databases. Because these requirements could not be satisfied, the research team concluded that an evaluation of multiple treatments is not feasible at this time.

The preceding pages have described four theoretical designs that could be used to compare the relative safety of different types of left turn phasing. As part of this project, two of the study designs were applied to existing data available from the signalized intersection databases and accident records. The two following sections describe a simple comparison of accident rates and a simple before/after comparison of accident rates. Both approaches used historical data.

ACCIDENT STATISTICS FOR A SIMPLE COMPARISON

One method of comparing the relative safety of different types of left turn phasing is to compare accident rates on approaches with one type of left turn phasing with accident rates on approaches with a second type of left turn phasing. This is the simple comparison design. Data acquired for the ADOT signalized intersections and the local jurisdiction intersections (see discussion on microcomputer databases in previous chapter) provided the opportunity to develop accident statistics and enable a comparison. Statistics were developed for different types of left turn phasing, varying numbers of opposing lanes (2 or 3), varying ranges of left-turn volume, and varying ranges of opposing volume.

Accident statistics were developed for left-turn accidents and were developed as an accident rate. The left turn accident rate is based upon the number of left turn accidents (as classified by the "manner of collision" on the accident report form) and the associated left turn volume. The rate is expressed in terms of number of left turn accidents per one million left turning vehicles.

Each sample used in developing the accident statistics represents a single approach at an intersection. A total of 523 samples (intersection approaches) were included in developing the accident statistics. Approaches with two opposing lanes had 329 samples; approaches with three opposing lanes had 194 samples. All approaches used for this analysis had a separate left turn lane.

For intersections on the state highway system, most samples represent a four-year accident history (1983 through 1986). For intersections in local jurisdictions, samples range from a minimum of 7 months to a maximum of 48 months (all in the period from 1981 to 1989). The "mean" accident rate is a weighted average which is weighted in proportion to the time period sampled on an approach.

The quality of the accident statistics is affected by the accuracy of the traffic volume information and the quality of the accident records system. A user of these statistics should be aware of these potential limitations. The accuracy of the left turn volumes and the accuracy of the volume of opposing traffic could vary depending upon the day of the week and the month of the year on which the count was made. Volumes were sometimes interpolated or extrapolated from count dates before and/or after the time period when the accident data were collected. Traffic volumes may have fluctuated during the four year period in which the accident data was collected (due to changes in the roadway network or changes in land use/development). In virtually all cases turning movement count volumes for a shorter number of hours during the day were expanded to estimate a 24 hour volume.

The quality of the accident records system is affected by underreporting, misclassification of accidents (the manner of collision, for example), and other factors.

Gross accident statistics are presented in Table 6. Statistics are presented for five types of left turn phasing: permissive; leading exclusive/permissive; lagging exclusive/permissive; leading exclusive; and lagging exclusive. Separate statistics are presented for locations having two opposing lanes of traffic and locations having three opposing lanes of traffic. The mean left turn accident rate is presented along with the sample size (N) on which that mean rate is based.

The following observations and conclusions can be made about the statistics that are not stratified by volume.

- The sample size for lagging exclusive phasing is too small to rely upon the average accident rates for comparison purposes.

Of the four remaining types of phasing -

- Leading exclusive phasing has the lowest left turn accident rate.
- When there are two opposing lanes, lagging exclusive/permissive has the worst accident rate.
- When there are three opposing lanes, leading exclusive/permissive has the worst accident rate.
- For two opposing lanes, the order of safety (from best to worst) is leading exclusive, permissive, leading exclusive/permissive, lagging exclusive/permissive. However, there is a small difference in the accident rate among the last three types of phasing.

TABLE 6
STATISTICS ON LEFT TURN ACCIDENT RATE

		Permissive	Leading Exclusive/ Permissive	Lagging Exclusive/ Permissive	Leading Exclusive	Lagging Exclusive
2 opposing lanes	m	2.62	2.71	3.02	1.02	2.09
	n	1.62	62	44	57	4*
3 opposing lanes	m	3.83	4.54	2.65	1.33	0.55
	n	25	52	35	80	2*

Left Turn Accident Rate is based upon the number of left turn accidents (Manner of Collision) and the associated left turn volume. The rate is in terms of accidents per million left turning vehicles. Each sample represents a single approach at an intersection.

* Sample size is too small to rely upon the average accident rate for comparison purposes.

- For three opposing lanes, the order of safety (from best to worst) is leading exclusive, lagging exclusive/permissive, permissive, leading exclusive/permissive.
- In three out of four cases accident rates are higher with three opposing lanes. The exception is for lagging exclusive/permissive phasing (although the difference in rates is small).

Tables 7 and 8 present similar accident statistics for various ranges of left turn volume (vehicles per day) and various ranges of opposing volume (vehicles per day). Opposing volume is defined as the through and right turn volume on the approach opposite the left turn movement.

The following observations and conclusions can be made about the statistics that are stratified by volume.

- The sample size for lagging exclusive phasing is too small to rely upon the average accident rates for comparison purposes.

Of the four remaining types of phasing -

- There are several cases where the sample size is 5 or less. It would be very risky to make comparisons with mean accident rates based upon a sample size of 5 or less. Therefor, no interpretations are made for these cases.
- Leading exclusive phasing has the lowest left turn accident rate in almost every case. This is true in every left turn volume range and every opposing volume range except one (19 out of 20 cases).
- When there are two lanes of opposing traffic, lagging exclusive/permissive tends to have the worst accident rate.
- When there are three lanes of opposing traffic, leading exclusive/permissive tends to have the worst accident rate.
- When there are two lanes of opposing traffic, the order of safety (from best to worst) tends to be leading exclusive, permissive, leading exclusive/permissive, lagging

TABLE 7
STATISTICS ON LEFT TURN ACCIDENT RATE STRATIFIED BY LEFT TURN VOLUME

Left Turn Vol.	Permissive		Leading Exclusive/ Permissive		Lagging Exclusive/ Permissive		Leading Exclusive		Lagging Exclusive	
	MEAN	N	MEAN	N	MEAN	N	MEAN	N	MEAN	N
0-1000	3.07	93	4	16	4.71	10	1.24	14	6.3	1
1000-2000	2.38	51	2.44	25	2.89	13	1.42	22	1.43	1
2000-3000	.87	13	2.43	16	2.66	9	51	13	.62	1
3000-4000	1.62	3	2.87	3	2.19	7	.52	2	N.A.	0
>4000	.45	2	.84	2	1.21	5	.24	6	0	1
Cumulative	2.62	162	2.71	62	3.02	44	1.02	57	2.09	4
	3 Opposing Lanes									
0-1000	4.21	8	4.33	17	1.11	7	1.37	12	1.66	1
1000-2000	3.51	12	5.94	8	4.34	12	1.09	23	0	1
2000-3000	4.06	5	3.98	11	2.87	6	1.26	26	N.A.	0
3000-4000	N.A.	0	3.98	11	2.03	6	. 84	12	N.A.	0
>4000	N.A.	0	5.27	5	1.67	4	92	7	N.A.	0
Cumulative	3.83	25	4.54	52	2.65	35	1.33	80	.55	2

Left Turn Accident Rate is based upon the number of left turn accidents (Manner of Collision) and associated left turn volume. The rate is in terms of accidents per million left turning vehicles. Each sam represents a single approach at an intersection.

Left Turn Volume is the 24 hour left turn volume.
Mean is the mean accident rate for the approaches in the sample.
N is the sample size.
Cumulative is the weighted average mean for all volumes.

TABLE 8
STATISTICS ON LEFT TURN ACCIDENT RATE STRATIFIED BY OPPOSING VOLUME

Oppos-ing -Vol.	Permissive		Leading Exclusive/ Permissive		Lagging Exclusive/ Permissive		Leading Exclusive		Lagging Exclusive	
	MEAN	N	MEAN	N	MEAN	N	MEAN	N	MEAN	N
0-5000	1.4	71	1.97	15	1.43	5	.23	9	0	1
5000-10000	1.98	58	2.92	21	3.26	15	.49	17	1.43	1
10000-15000	3.54	17	2.89	19	3.47	18	2.07	19	3.46	2
15000-20000	6.08	8	2.33	5	3.54	2	.64	06	N.A.	0
>20000	4.99	.8	4.54	2	2.57	2	.69	.06	N.A.	0
Cumu-lative	2.62	162	2.71	62	3.02	42	1.02	57	2.09	4
3 Opposing Lanes										
0-5000	3.28	5	3.91	2	N.A.	0	.25	3	1.66	1
5000-10000	2.05	. 7	4.78	10	2.57	.8	1.01	12	N.A.	0
10000-15000	4.83	5	4.32	.12	3.3	11	.98	22	.0	1
15000-20000	6.61	.4	4.98	.16	2.51	10	1.15	17	N.A.	0
>20000	2.78	.4	4.07	12	1.88	6	1.45	26	N.A.	0
Cumu-lative	3.83	25	4.54	52	2.65	35	1.33	80	.55	2

Left Turn Accident Rate is based upon the number of left turn accidents (Manner of Collision) and the associated left turn volume.rate is in terms of accidents per million left turning vehicles. Each sample represents a single approach at an intersection.

Opposing Volume is the 24 hour opposing volume (through and right turning vehicles on the opposite approach).
Mean is the mean accident rate for the approaches in the sample.
N is the sample size.
Cumulative is the weighted average mean for all volumes.

exclusive/permissive. However, there is a small difference in the accident rate among the last three types of phasing.

- When there are three lanes of opposing traffic, the order of safety (from best to worst) tends to be leading exclusive, lagging exclusive/permissive, permissive, leading exclusive/permissive.
- Generally, accident rates are higher for three opposing lanes of traffic than for two opposing lanes of traffic. This is true in 30 out of 40 "cases" (combinations of phasing and volume). Lagging exclusive/ permissive tends to be an exception to this rule.
- Some trends are apparent in the accident rate as a function of volume.
  - For all four types of phasing (permissive, leading exclusive/permissive, lagging exclusive/permissive, and leading exclusive), with **two** opposing lanes of traffic, the accident rate **decreases** as left turn volume **increases**. Figures 1 - 3 plot left turn accident rate as a function of left turn volume for three of these conditions (permissive phasing, lagging exclusive/permissive, and leading exclusive).
  - For all four types of phasing (permissive, leading exclusive/permissive, lagging exclusive/permissive, and leading exclusive), with **two** opposing lanes of traffic, the accident rate **increases** as opposing volume **increases**.
  - For **three** opposing lanes of traffic there is only one apparent trend in left turn accident rate as a function of volume. For permissive left turn phasing the accident rate **increases** as opposing volume **increases**.

The study team also looked at accident statistics for conditions that were stratified by both left turn volume and opposing volume at the same time. This would allow one to pick a range of left turn volume, a range of opposing volume, a number of opposing lanes, and a type of phasing and determine the accident rate for those conditions. For example, the condition of: left turn volumes between 0 and 1000 per day, opposing volume between 0 and 5000 per day, two opposing lanes, and permissive left turn phasing had a left turn accident rate of 1.53 (based upon a sample size of 44).

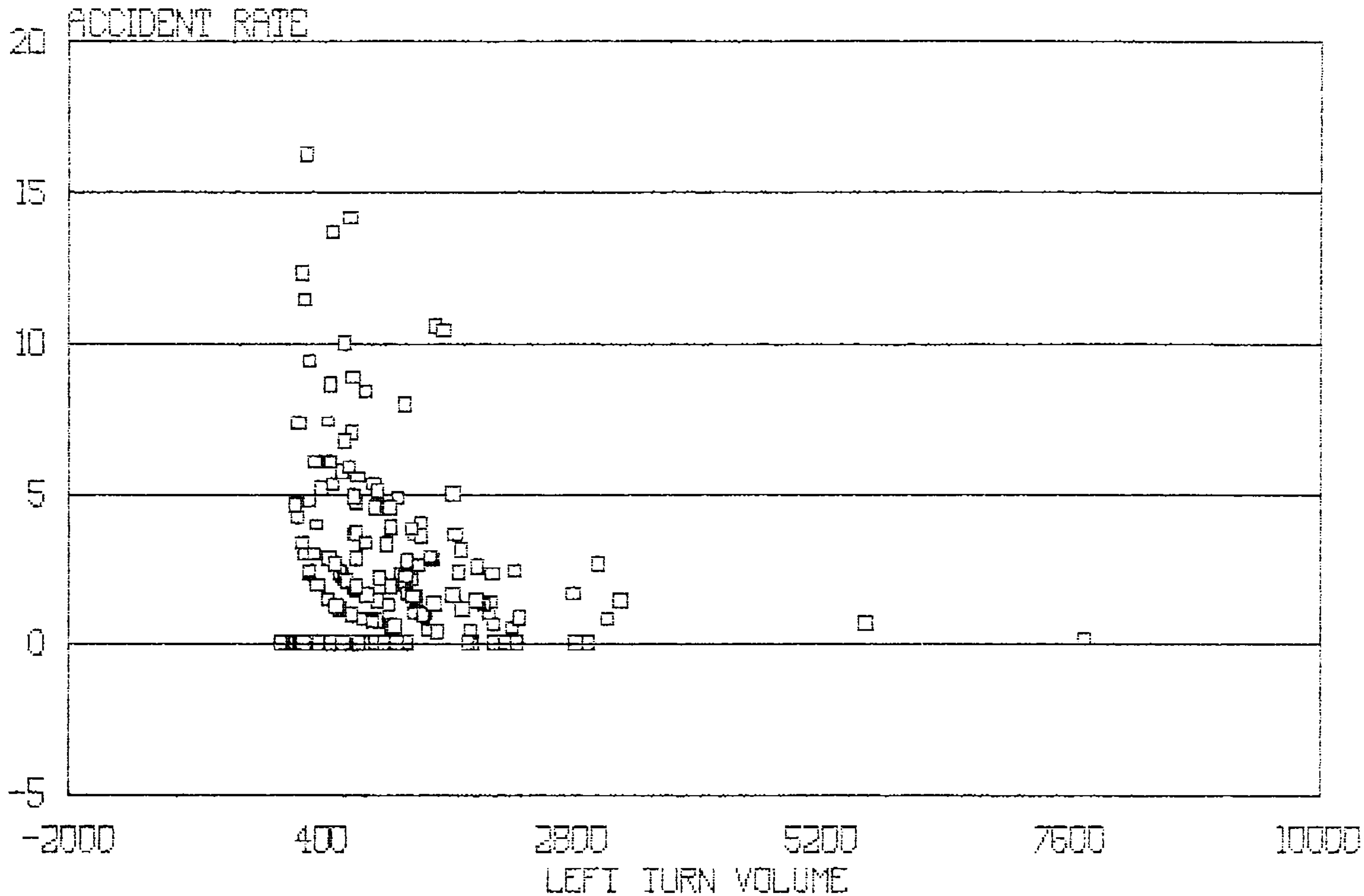

FIGURE 1 - LEFT TURN ACCIDENT RATE FOR PERMISSIVE LEFT TURN PHASING - 2 OPPOSING LANES

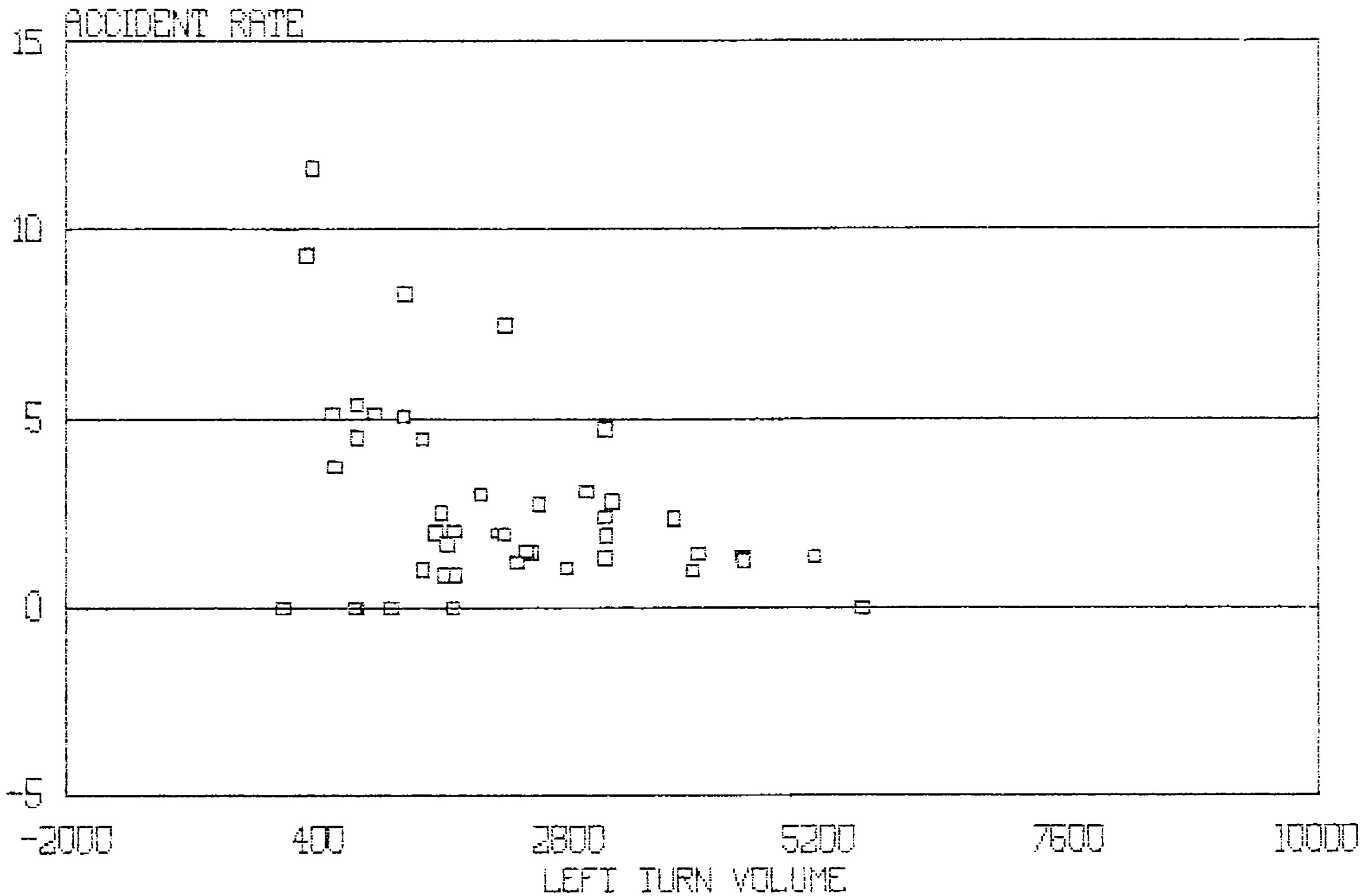

FIGURE 2 - LEFT TURN ACCIDENT RATE FOR LAGGING EXCLUSIVE/PERMISSIVE LEFT TURN PHASING - 2 OPPOSING LANES

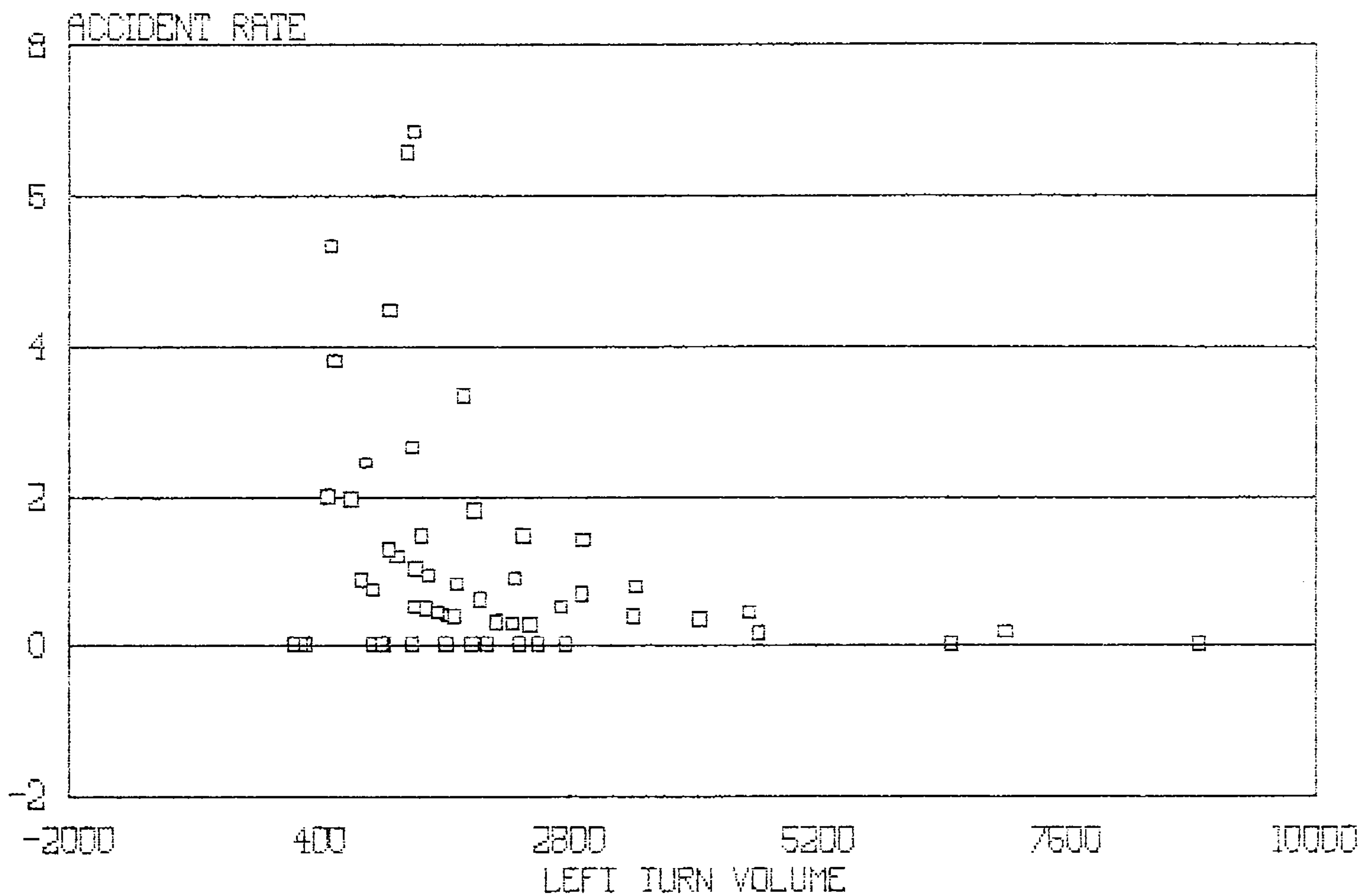

FIGURE 3 - LEFT TURN ACCIDENT RATE FOR LEADING EXCLUSIVE LEFT TURN PHASING - 2 OPPOSING LANES

The availability of accident rate information of this form would be a tremendous asset to the traffic engineer. Unfortunately, stratifying conditions to this level of detail resulted in very small sample sizes for most cases. Eighty-eight percent of the cases had a sample size of 5 or less. Forty-two percent of the cases had a sample size of zero.

It is important that the reader understand the limitations of all of the accident rate information presented in this section. There are weaknesses in the relatively simple method that was used to obtain accident information and compute accident rates. The quality of the accident rates - and the reasons that quality might be degraded - were described earlier in this section. Beyond this, there are other limitations. The intersections used to develop these accident statistics were **not** randomly selected. They are simply the intersections for which jurisdictions were able to provide all of the necessary data. The time period used for accident information was not the same for all of the locations. Most of the intersections on the ADOT system had data available for a four year period from 1983 through 1986. The time period for local intersections varied considerably; the time period from 1985 to 1988 was most common. Although efforts were made to make intersections as alike as possible (in terms of type of phasing, number of opposing lanes, left turn volume, opposing volume, and the existence of a separate left turn lane), there may still be differences in intersection characteristics among the different groups.

ACCIDENT STATISTICS FOR CONVERSIONS

A second means of comparing the relative safety of different types of left turn phasing is to compare the accident experience before and after a location had been converted from one type of phasing to another. To make this type of comparison, additional information was obtained on conversions from one type of phasing to another for both ADOT roadway intersections and local jurisdiction intersections.

Among the sources of data provided by ADOT to develop the microcomputer database was: "Signalized Intersection Tabulation, Left Turn Phasing, Intersections With Left Turn Phasing" (source number 10, Appendix B). This tabulation identified 61 intersections on the ADOT roadway network which had the type of left turn phasing changed at some point in time. The dates of these conversions were spread out over a long period of time -- from 1955 to 1985. Twenty-nine of the 61 intersections had the type of phasing changed prior to 1980. Among the remainder were thirteen intersections, in Tucson and Pima County, which were changed from leading to lagging operation in mid-1985. Most of these locations were used, in conjunction with conversion locations in local jurisdictions (described below), to develop before and after accident statistics.

As noted in the preceding chapter, local jurisdictions were solicited for information on intersections that had been converted from one type of phasing to another. This information was collected through the forms labeled as Attachments 2 and 3 in Appendix C. Information was collected for intersection approaches that had a separate left turn lane, either two or three lanes of opposing traffic, and had turning movement counts available. The study team acquired accident data from the ALISS accident records system.

Six local jurisdictions provided information. The number of intersection approaches in each jurisdiction that were usable for the analysis were as follows.

ADOT	15
Glendale	12
Maricopa County	0
Mesa	0
Pima County	3
Scottsdale	157
Tempe	7
TOTAL	194

The local jurisdiction conversions which were used for a before and after analysis included some conversions that were made as early as 1984 and several that were made as late as late 1988 and early 1989. For each conversion, four years of before accident data were used if it was available. Four years of after accident data were used in those cases where it was available. In many cases, such as the conversions done in late 1988 and early 1989, a shorter after period was available. In most of these cases, accident data through the end of 1989 was acquired. A driver adjustment period of at least 60 days was allowed after a conversion. No accident data was used from this 60 day period.

With five different types of left turn phasing, there are twenty different conversions that could take place. The different types of conversions are not equally popular. For example, it is rare to convert from some more restrictive type of phasing to permissive phasing. As a second example, lagging operation is not commonly used in Arizona and, therefore, there have been few conversions to lagging phasing. Among the 194 approaches used in the statistical evaluation, the more popular types of conversion and their frequency are noted below.

Permissive to Leading Exclusive/Permissive	20
Permissive to Lagging Exclusive/Permissive	17
Leading Exclusive/Permissive to Permissive	17
Leading Exclusive/Permissive to Lagging Exclusive/Permissive	73
Leading Exclusive to Leading Exclusive/Permissive	25
Leading Exclusive to Lagging Exclusive/Permissive	15
Leading Exclusive to Lagging Exclusive	22

These seven types of conversion accounted for 189 out of the 194 intersection approaches. Eleven out of the 20 possible types of conversions had never been done in the field for reasons such as those noted above.

Tables 9 and 10 present before and after accident statistics for the 194 approaches that were converted from one type of left turn phasing to another. The left turn accident rate is based upon the number of left turn accidents (Manner of Collision) and the associated left turn volume. The rate is in terms of accidents per million left turning vehicles. Each sample represents a single approach at an intersection. Data is presented on the before and the after accident rates; the total number of months of data in the before period and in the after period; and the number of intersection approaches on which the statistics are based. Table 9 presents statistics for intersections with two opposing lanes of traffic and Table 10 presents statistics for intersections with three opposing lanes of traffic.

The following observations and conclusions can be made for the conversions made at approaches having two opposing lanes of traffic.

TABLE 9

BEFORE AND AFTER LEFT TURN ACCIDENT RATES FOR APPROACHES CONVERTED FROM ONE TYPE OF PHASING TO ANOTHER - 2 OPPOSING LANES

BEFORE TYPE OF PHASING \ AFTER TYPE OF PHASING	Permissive	Leading E/P	Lagging E/P	Leading Exclusive	Lagging Exclusive
Permissive	X	4.77 3.49 608 425 17	5.44 4.16 359 131 9		
Leading E/P	2.07 2.66 462 340 14	X	3.10 2.25 1170 622 35		
Lagging E/P			X		
Leading Exclusive		0.93 3.11 144 70 3	0.38 1.57 220 67 6	X	1.46 1.91 346 144 10
Lagging Exclusive					X

KEY

A	B
C	D
E	

A = Before left turn accident rate
B = After left turn accident rate
C = Total number of months of before data
D = Total number of months of after data
E = Number of intersection approaches

Left Turn Accident Rate is based upon the number of left turn accidents (Manner of Collision) and the associated left turn volume. The rate is in terms of accidents per million left turning vehicles. Each sample represents a single approach at an intersection.

TABLE 10

BEFORE AND AFTER LEFT TURN ACCIDENT RATES FOR APPROACHES CONVERTED FROM ONE TYPE OF PHASING TO ANOTHER - 3 OPPOSING LANES

BEFORE TYPE OF PHASING \ AFTER TYPE OF PHASING	Permissive	Leading E/P	Lagging E/P	Leading Exclusive	Lagging Exclusive
Permissive	X	4.64 5.55 144 77 3	8.75 1.37 194 59 8	18.96 0.36 87 67 3	
Leading E/P	2.25 5.85 82 73 3	X	4.54 2.74 1181 831 38	7.08 0.75 12 68 2	
Lagging E/P			X		
Leading Exclusive		1.40 4.72 998 594 22	2.13 1.03 329 84 9	X	0.35 0.35 390 114 12
Lagging Exclusive					X

KEY

A	B
C	D
E	

A = Before left turn accident rate
B = After left turn accident rate
C = Total number of months of before data
D = Total number of months of after data
E = Number of intersection approaches

Left Turn Accident Rate is based upon the number of left turn accidents (Manner of Collision) and the associated left turn volume. The rate is in terms of accidents per million left turning vehicles. Each sample represents a single approach at an intersection.

Each before case or after case has at least five and one-half approach years of data on which the statistics are based.

The following conversions resulted in decreases in the left turn accident rate.

From permissive to leading exclusive/permissive

From permissive to lagging exclusive/permissive

From leading exclusive/permissive to lagging exclusive/permissive

The following conversions resulted in increases in the left turn accident rate.

From leading exclusive/permissive to permissive

From leading exclusive to leading exclusive/permissive

From leading exclusive to lagging exclusive/permissive

From leading exclusive to lagging exclusive

The statistics for conversions: from permissive to leading exclusive/permissive; and from leading exclusive/permissive to permissive reinforce each other. Both suggest that leading exclusive/permissive is safer than permissive.

The following observations and conclusions can be made for the conversions made at approaches having three opposing lanes of traffic.

Each before case or after case has at least five approach years of data on which the statistics are based.

The following conversions resulted in decreases in the left turn accident rate.

From permissive to lagging exclusive/permissive

From permissive to leading exclusive

From leading exclusive/permissive to lagging exclusive/permissive

From leading exclusive/permissive to leading exclusive

From leading exclusive to lagging exclusive/permissive

The following conversions resulted in increases in the left turn accident rate.

From permissive to leading exclusive/permissive

From leading exclusive/permissive to permissive

From leading exclusive to leading exclusive/permissive

The statistics for conversions: from permissive to leading exclusive/permissive; and from leading exclusive/permissive to permissive contradict each other. The former suggests that permissive phasing is safer. The latter suggests that exclusive/permissive phasing is safer. It is possible that conditions at these two sets of intersections are different (traffic volumes, for example) and that these differences may account for the contradiction.

The statistics for conversions: from leading exclusive to leading exclusive/permissive; and from leading exclusive/permissive to leading exclusive reinforce each other. Both suggest that leading exclusive is safer than leading exclusive/permissive.

It is possible to compare the cases with two opposing lanes of traffic to those with three opposing lanes of traffic. In most cases the trends are the same. For example, a conversion from leading exclusive/permissive to permissive will result in an increased accident rate for approaches with two opposing lanes of traffic *and* for approaches with three opposing lanes of traffic.

There are two cases, however, where the trends are opposite. For two opposing lanes of traffic a conversion from permissive to leading exclusive/permissive results in a decrease in accident rate. The opposite is true for three opposing lanes. This finding, for three opposing lanes, supports the view of some traffic engineers who are reluctant to use exclusive/permissive phasing when there are three opposing lanes. They are reluctant to do so because a larger gap is required; it is more difficult for the driver to judge an acceptable gap; and there is a greater chance that an oncoming vehicle in one lane will be masked out by a vehicle in another lane.

The other case in which trends are opposite is conversions from leading exclusive to lagging exclusive/permissive. For two opposing lanes this results in an increase in accidents. For three opposing lanes it results in a decrease. The data alone do not suggest an explanation for these opposite trends. An analysis of the number of turns during the permissive period may provide an explanation. It may be that with three lanes, fewer drivers are willing to take a chance and turn during the permissive portion of the phase.

SELECTION OF RECOMMENDED DESIGN

Four candidate designs were described early in this chapter. They are:

Simple comparison of accident rates

Simple before/after design

Before/after design with randomized control group

Evaluation of multiple treatments.

As stated earlier in this chapter, the research team concluded that an evaluation of multiple treatments is not feasible at this time. Of the three remaining candidate designs, the research team initially recommended that the before/after design with randomized control group be the recommended design. This decision was based primarily on the requirement in the contract that a "statistically valid" study design be developed. In the opinion of the research team, this approach presented the strongest design to meet that objective.

Upon review, the Arizona Department of Transportation concluded that the number of intersections required to conduct a before/after design with randomized control group was impractically large. ADOT then directed that both the simple comparison approach and the simple before/after design approach (for intersections which have been or will be converted) be used in the future research project. The choice of these approaches represents a compromise between designing an approach that is as statistically rigorous as possible and an approach which is practical to execute.

The intent of the current research project was to recommend a design for comparing the relative safety of different types of left turn phasing. The intent was to recommend a design which would be used in the future research project which was being designed in the current effort. Based upon our review of the safety evaluation designs which could be used, and the results of the accident statistics compiled in the current effort, the study team recommends that a future safety evaluation not be conducted. Rather, the study team recommends that the accident statistics compiled in the current effort be used in developing the warrant or guideline for selecting the type of left turn phasing. In the opinion of the study team, a future safety evaluation would require a significant amount of resources and would likely result in little or no improvement over the accident statistics that were compiled under the current effort. The following paragraphs spell out a justification for this recommendation.

Simple Comparison Design

It is worthwhile to review some of the major findings from the accident statistics compiled from historical information.

523 intersection approaches were used.

The gross statistics, presented in Table 6, show that:

the sample size is adequate (except for lagging exclusive phasing);

there are distinct differences in accident rate for different types of left turn phasing;

there are distinct differences in accident rate for 2 opposing lanes compared to 3 opposing lanes.

The statistics stratified by volume, show that:

there are distinct differences depending upon the magnitude of the left turn volume;

there are distinct differences depending upon the magnitude of the opposing volume.

It is clear that volume has a significant impact on accident rate.

The **perfect** approach for using the simple comparison design would consist of the following steps.

Begin with the universe of all signalized intersection approaches in Arizona.

Eliminate those approaches that did not have a separate left turn lane and those that had only one or more than three opposing lanes of traffic.

Partition the remaining intersection approaches into ten groups based upon the five types of left turn phasing and whether an approach had 2 or 3 opposing lanes.

Subdivide each group into volume ranges for left turn volume and for opposing volume.

For each subgroup, randomly select N approaches to be evaluated (N being large enough to provide statistically valid results).

Collect data, compute accident rates for each subgroup, and compare different types of left turn phasing.

Unfortunately, it would not be feasible to conduct the perfect approach described above. The biggest hurdle is that the databases compiled in this project include only less than one-forth of all signalized intersections in the state. And, even among those, complete information is not available on the intersection geometry, phasing, and volume for many of the [ADOT] intersections. Thus, it would be possible to achieve a random sample of intersections only if substantial additional effort was devoted to collecting geometry, volume and phasing information for over three-fourths of Arizona's signalized intersections.

The alternative to the above perfect approach would be to use the intersections in the databases for which we have the appropriate geometry, volume and phasing data. These intersections, or a subset thereof, could be selected and additional data could be collected to improve the accident statistics that have already been developed. Improvements in the statistics could result from:

confirmation, or lack thereof, from field visits that current geometry and phasing are what we believe them to be;

collection of new turning movement count data (several hours of counts at each location) which would provide a more reliable count for computing accident rate.

These represent the potential gains.

There are disadvantages to going out and collecting additional data.

The statistics we now have are based on the equivalent of over 130 intersections. Data would need to be collected at a comparable number of intersections to be able to subdivide intersections into groups based upon types of phasing, number of opposing lanes, and stratifications by volume. There is obviously significant cost and effort associated with the data collection for a large number of intersections. It is estimated that the site visits, turning movement counts, and computation of accident rates would cost about $50,000.

It would take time to acquire these improved results (one to two years if contracting is done through a request for proposals process).

The statistics would still be based on a nonrandom sample.

If, as an alternative to collecting data at a large number of intersections, data is collected at a smaller number of intersections, then there would not be as much confidence in the calculated means for the accident rates.

In comparing the potential gains with the disadvantages, it must be asked if the potential gains are achieved at a reasonable cost. In the opinion of the research team, they are not.

Simple Before/After Design

Accident statistics, based on historical information on conversions, were based upon 194 intersection approaches that were converted. These statistics provided a before and after comparison of accident rates at converted locations.

Like the simple comparison design, these accident statistics could be improved upon. The advantages would include:

> confirmation, or lack thereof, from field visits to these 194 locations, that current geometry and phasing are what we believe them to be;
>
> collection of new turning movement count data (several hours of counts at each location) which would provide a more reliable count for computing accident rate;
>
> the addition of 99 intersection approaches which are planned to be changed by March, 1991.

Again, there are disadvantages associated with the additional data collection. They include the cost of data collection and the time required. In the opinion of the research team, the potential improvements in the statistics would not be achieved at a reasonable cost.

It is for these reasons that the study team recommends that a future safety evaluation not be conducted. Rather, the study team recommends that the accident statistics compiled in the current effort be used in developing the warrant or guideline for selecting the type of left turn phasing. The work plan presented in Chapter 7 will reflect this recommendation.

CHAPTER 4 - VALIDATION TESTING OF THE TEXAS MODEL

One of the tasks of this project (Task 3) was to determine an analytical process for evaluating intersection operations. Chapter 5 will describe, in further detail, various approaches that were considered for evaluating intersection operations. One of these approaches was to use an intersection simulation model to evaluate differences in intersection operations associated with different types of phasing. The research team felt that this approach had a good chance of success and that the TEXAS simulation model was a good candidate.

An important prerequisite to use of a model for this application is to validate and/or calibrate the model to assure that it reflects real world operation and to promote confidence in its performance. For this reason, the TEXAS model was subjected to validation testing in this project. This chapter summarizes the results of the validation testing (details of the validation testing are presented in Appendix D). The results of this analysis will provide a natural lead-in to Chapter 5 which will discuss other approaches that were considered for evaluating intersection operations.

Validation testing was very extensive and documentation of that testing and the results are quite lengthy. Due to its length, the documentation is presented separately in Appendix D.

The evaluation showed mixed results. In most cases, the TEXAS model badly overestimated left turn delay for all three types of left turn phasing tested (permissive, leading exclusive, leading exclusive/permissive). For through traffic the TEXAS model provided good estimates of through delay overall. The model tended to overestimate delay when average delay per vehicle was low and tended to underestimate delay when average delay per vehicle was high. The principal shortcoming is that the TEXAS model does not replicate real world behavior of left turning vehicles at signalized intersections. For this reason, the TEXAS model, in its current form, can not be used to evaluate differences in intersection operations due to differences in left turn phasing. Therefore, some other approach must be used to evaluate differences in operating characteristics. As noted in the section on "Recommendations for Further Study," the study team recommends that a similar validation be conducted for the NETSIM model to see if it can be used to evaluate differences in operation.

Task 10 of this project was to present a workshop on the TEXAS model including its design, its capabilities, and how it can be used. Due to the findings of the validation study, it became inappropriate to present a workshop on the TEXAS model.

CHAPTER 5 - APPROACHES FOR EVALUATING THE OPERATING CHARACTERISTICS OF DIFFERENT TYPES OF LEFT TURN PHASING.

INTRODUCTION

The objective of evaluating operating characteristics is to quantify the differences in operating characteristics for the three different types of left turn phasing and for leading versus lagging operation. Differences in operating characteristics can be measured in a variety of ways. One way would be to measure differences in vehicle delay when different types of left turn phasing are used. The ultimate goal is to combine information on relative safety (see Chapter 3) and operating characteristics to develop warrants or other means of deciding when different types of left turn phasing should be used.

As noted above, operating characteristics can be measured in a number of ways, using a variety of measures of effectiveness. Among the possibilities are:

delay to all vehicles approaching the intersection

delay to through and right turning vehicles

delay to left turning vehicles

average or maximum queue length

the number of stops per vehicle

vehicle operating cost

fuel consumption

vehicle emissions

Measures such as delay, queue length, and number of stops per vehicle can be measured directly in the field. Measures such as vehicle operating cost, fuel consumption, and vehicle emissions cannot be measured directly in the field and must be computed based on factors which are directly measured such as delay. Any of the measures of effectiveness listed above could be used for a warrant or other means of deciding when different types of left turn phasing should be used. A warrant, then, would be based upon "optimizing" intersection operation in terms of some combination of the operating measures of effectiveness listed above and relative safety.

There are two significant challenges to the development of warrants for left turn phasing. The first is to set up the research design so that the results confidently show that operational (and safety) differences are primarily or solely due to differences in left turn phasing and not due to other extraneous factors. Observed differences in delay, for example, must be the result of differences in left turn phasing and not due to differences in cycle length, signal timing, or progression patterns. The second challenge is to develop a warrant which is simple enough that it can be easily used by the traffic engineer. This is a major challenge because there are several factors which significantly affect intersection operation and which influence the operational efficiency of left turn phasing. The number of opposing lanes, approach speed, left turn volume, opposing volume, cycle length, g/c ratios, phasing patterns, progression, arrival patterns and other factors all have an influence. The number of possible combinations of these factors is clearly quite large. The challenge is to develop a warrant or guidelines which can consider these factors, not be cumbersome to use, and yet still identify the "best" type of left turn phasing for a large variety of situations.

BASIC INTERSECTION CHARACTERISTICS TO BE CONSIDERED

Table 11 presents an extensive list of intersection characteristics that can influence intersection operation. Obviously, some of these characteristics have a major influence while others have a minor influence or none at all. The following paragraphs recommend which of the characteristics should be considered in developing warrants or guidelines.

The research team recommends that the future research project develop warrants or guidelines which will encompass the following types of left turn phasing.

a. permissive

b. leading exclusive

c. lagging exclusive

d. leading exclusive/permissive

e. lagging exclusive/permissive

f. left turn denial

TABLE 11

BASIC INTERSECTION CHARACTERISTICS

- * Type of left-turn phasing
  - permissive
  - leading exclusive
  - lagging exclusive
  - leading exclusive/permissive
  - left turn denial
- * Number of opposing lanes
- * Presence or absence of a separate left turn lane
- * Volume
  - left turn volume
  - volume of opposing traffic
- * Approach speed
- * Progression or lack of progression; arrival patterns
- * Signal timing and phasing
  - cycle length
  - g/c ratio
  - type of phasing arrangement
  - type of controller
- * Sight distance
- Number of approaches
- Crossing angle
- Lane width
- Length of left turn lane
- Approach grade
- Location and arrangement of signal heads (signal display)
- Other traffic control devices
- Detector placement for left turn lane
- Pedestrian activity, pedestrian actuation
- Land Use

* Denotes those characteristics which should be considered in developing warrants or guidelines.

The guidelines should cover intersections with two and three through (opposing) lanes. Signalized intersections with only one through lane are relatively rare in Arizona. Where they do occur, traffic volumes are low enough and left turn volumes are low enough that there is usually no need for separate left turn phasing. Where volumes are higher, this will often result in an intersection widening, thus creating two or three opposing lanes.

The guidelines should cover only those intersections/approaches with a separate left turn lane. Arizona's relatively new street network is characterized by wide rights-of-way. Seldom is there not adequate street width or right of way to provide a separate left turn lane. This provision would greatly simplify the warrant.

The complete range of volumes (both left turn and through) which exist at signalized intersections should be covered.

Approach speed has been shown to have an influence on the relative safety of different types of left turn phasing. Similarly, it has an impact on intersection operation. Approach speed should be considered.

Stonex's study (17) at 44th Street and Thomas Road in Phoenix showed that arrival patterns had a major influence on the differences in intersection operation between permissive and exclusive/permissive left turn phasing. If possible, warrants or guidelines should consider progression and arrival patterns.

Signal timing and phasing have a strong influence on intersection operation and delay. Cycle length; g/c ratios; lost time; and the use of split, dual, and other phasing arrangements all have an impact. The optimum cycle length for a two-phase operation (permissive left turns), a four phase operation (exclusive left turns), and an eight phase operation (also exclusive) will each be different. The type of controller - fixed-time, semi-actuated, or actuated - also influences operation. Each of these factors is significant. If possible, they should be considered in developing warrants or guidelines.

Sight distance available to left turning vehicles should be considered in developing warrants or guidelines. The guidelines should allow for exclusive left turn phasing if the sight distance available for left turning vehicles is inadequate.

The characteristics described above are those which the research team recommends be considered in developing warrants or guidelines. While the remaining characteristics listed in Table 11 may have some impact, the research team believes that the impact is relatively small. In the interest of keeping a warrant fairly simple and easy to apply these characteristics should not be included.

ALTERNATIVE APPROACHES FOR EVALUATING OPERATING CHARACTERISTICS

The research team has identified four alternative approaches for evaluating operating characteristics under each of the types of left turn phasing. Each approach has advantages and disadvantages. This section of Chapter 5 describes each of the four approaches.

Matched Pairs of Intersections

This approach was used by Matthias and Upchurch (15) to compare different types of left turn phasing in 1984. Using this approach an attempt is made to identify pairs (or triplets) of intersections which have different types of left turn phasing but which are otherwise identical in their characteristics. The approach was successfully used by Matthias and Upchurch in identifying some basic or gross differences between different types of left turn phasing. While it is fairly easy to match intersections in terms of number of opposing lanes, presence of a separate left turn lane, and approach speed, it is difficult to impossible to match intersections in terms of volume, arrival patterns, and the basic aspects of signal timing. For example, it is difficult to find existing permissive left turn intersections which have traffic volumes (left turn and through) as high as those at exclusive left turn intersections. Volume, arrival patterns, and signal timing all have an important influence on intersection operation. Thus, if these are not matched, it is difficult to conclude that differences in intersection operation are solely due to differences in left turn phasing.

It is difficult to impossible to statistically validate or prove what part of the differences in intersection operation are due to differences in left turn phasing.

An advantage of using matched pairs of intersections is a higher probability of locating study sites than a before and after type of study. In a before and after type of study, intersections must be found that jurisdictions have converted or are willing to convert from one type of left turn phasing to another.

Before/After Approach

A before/after type of study is able to overcome some of the disadvantages of a matched pair type of study. With this approach there is the potential ability to keep nearly all other intersection characteristics the same while changing the type of left turn phasing. This approach was used by Stonex (17) at 44th Street and Thomas Road in Phoenix.

With this approach some factors may be beyond the control of the researcher. Traffic volumes may change between the before and after period. Stonex, for example, found a statistically significant increase in left turn volume (left turns became easier to perform). Cycle length, g/c ratios, and arrival patterns may change unless the research team is able to exercise control over these. In the Stonex study each of these did change. The change in arrival pattern (due to the fact progression existed in the before phase but not the after phase) had a major impact on intersection delay.

A disadvantage of this approach is that a jurisdiction must be willing to convert an intersection from one type of left turn phasing to another. If jurisdictions are not willing to make conversions then no study can be done. Beyond this, those intersections which jurisdictions are willing to convert are likely to be those that have good "potential" for successful conversion. Jurisdictions are not likely to convert intersections that have poor "potential" for successful conversion. Thus, data would not be collected from those intersections which were judged to be poor candidates when, in fact, they might benefit from conversion.

A further disadvantage is that it is unlikely that a site would be found where all three types of phasing (permissive, exclusive/permissive, and exclusive) could be tested. Jurisdictions would probably be reluctant to make multiple changes in a short period of time due to the risk of driver confusion.

For both a before and after study and the matched pairs approach it may not be possible to find enough intersections, with the desired characteristics, for conversion. It would be desirable, in a research study, to be able to evaluate a range of intersection characteristics as noted in Table 11. It may not be possible to locate enough intersections to be able to evaluate a varying number of approach lanes, varying approach speeds, different arrival patterns, and differences in signal timing and phasing.

Data Collection Methods for the Matched Pair and Before/After Approaches

Data could be collected manually in the field or a permanent record of intersection operation could be recorded using time-lapse photography. Manual data collection could consist of a standard delay study based on counts of the number of stopped vehicles at prescribed intervals. Queue lengths would also be observed as part of this method. The manual data collection method is labor intensive and does not provide a permanent record which can be reviewed from time to time.

Time-lapse photography provides a permanent record and also allows additional data to be easily acquired such as the number of vehicles stopped or the number of vehicles not stopping. Capturing data from the film is labor intensive but the approach is probably more accurate.

Both data collection methods allow delay and queue length information to be acquired directly. Time lapse photography allows the number of vehicles stopped or not stopping to be acquired as well as the number of stops per vehicle. Other measures of effectiveness of intersection operation can be computed based upon delay data. Fuel consumption, vehicle emissions, and vehicle operating cost can be estimated in this way.

Computer Simulation

Computer simulation can overcome the disadvantages of the matched pair and before and after approaches. Using computer simulation the researcher has the ability to keep all other intersection characteristics constant while evaluating the differences in intersection operation due to different types of left turn phasing. Intersection geometry, traffic volume, approach speed, and arrival patterns can remain the same while the type of phasing is changed. Signal timing can remain the same except for those aspects which must change in order to implement a type of phasing. As an alternative, signal timing parameters can change to provide the optimum timing for each type of left turn phasing (the optimum cycle length might be longer for exclusive phasing than for permissive, for example). The researcher is not hampered by a lack of intersections or the reluctance of jurisdictions to convert intersections.

A further advantage of computer simulation is that a wide range of through and left turn volumes can be evaluated. A wider range of volumes, and a wider range of combinations of left turn and through volumes, than might be found at a single intersection in the field can be simulated. Finally, data collection is much easier and less expensive. Basic M.O.E.s such as delay, queue length, number of stops per vehicle, fuel consumption and emissions can all be generated directly by simulation programs.

A disadvantage of computer simulation is the lack of confidence, on the part of some practitioners, in the ability of simulation models to accurately represent real-world operation. Model validation can overcome this lack of confidence.

There are two simulation models which have the ability to model signalized intersections, the TEXAS model and NETSIM. Both are microscopic simulation models which have the ability to simulate permissive, exclusive, and exclusive/permissive left turn phasing. As noted in Chapter 4 and Appendix D, the TEXAS model was extensively tested in this research project to determine its suitability for this application. Although the TEXAS model was not found to be suitable, the research team believes that NETSIM can be validated. Although NETSIM has not been used for this application before, the research team believes that it would also be suitable.

Of the three approaches described thus far - matched pairs, before and after, and computer simulation - the research team believes that computer simulation is the best approach. It offers significant practical advantages over the methods that employ field data collection. In addition, the statistical validity of the results is easier to demonstrate with computer simulation. With simulation, long simulation runs and/or multiple simulation runs can be used to overcome short term variances in output statistics. With field data collection the number of samples, and hence, data collection costs, must be increased to produce statistically valid results. If employed, the operational characteristics generated by simulation can in turn be used to establish warrants or guidelines.

A "matched pairs" approach, a "before/after" approach and computer simulation each have the potential to evaluate the operating characteristics of various types of left turn phasing. However, with each of these it is virtually impossible to satisfy one of the challenges described in the introduction of this chapter. That challenge is to develop a warrant which is simple and easy to use while still considering those *several* factors that significantly affect intersection operation. The number of possible combinations of opposing lanes, approach speed, left turn volume, opposing volume, cycle length, g/c ratio, phasing patterns, progression, and arrival patterns makes it quite difficult to develop tables, figures, nomographs and other ways to easily select the "best" type of left turn phasing for a large variety of situations. For that reason a fourth approach for evaluating operating characteristics and selecting the "best" type of left turn phasing has been developed. It is described in the following section.

Simulate Individual Intersections

The basic concept behind any traditional warrant is that it allows the traffic engineer to predict, based on an easily used tool (the warrant), what type of control will result in the "best" operation. Thus, if a traffic signal volume warrant is applied and the volumes satisfy the warrant, this is a predictor that the intersection will operate better with signal control than it would with sign control. For left turn signal phasing we wish to develop an analogous tool which can be used to predict which type of left turn phasing will work "best." Or, as stated at the beginning of this chapter, "The ultimate goal is to ... develop warrants *or other means* of deciding when different types of left turn phasing should be used."

The approach of simulating individual intersections does not lead to development of a warrant. It does, however, provide *other means* of deciding which type of left turn phasing should be used at a particular intersection. The approach described below is possible because of two factors that did not exist when our more traditional traffic control warrants were developed.

1. Most traffic engineering agencies and personnel now have microcomputer capability.

2. An intersection simulation model which can simulate left turn phasing is now available.

The suggested approach is to provide the traffic engineer with the capability to simulate intersection operation using different types of left turn phasing. Intersection geometry, traffic volumes, and signal timing parameters would all be selected by the traffic engineer. The traffic engineer could then compare output statistics and measures of effectiveness to select the best type of left turn phasing.

It is the recommendation of the research team that this approach be used. First, the NETSIM model must be validated to confirm that it does replicate intersection operation for different types of left turn phasing. Then, the future research project would take the microcomputer version of NETSIM and "package" it so that traffic engineers could easily use it to evaluate different left turn options. Documentation and instructions would be prepared. An explanation of how to interpret the output and how to use the output to select the appropriate type of left turn phasing would be included. Chapter 7 - "Proposed Work Plan" - presents more detail on what would be developed in the future research project.

CHAPTER - 6 - CRITERIA AND APPROACH TO BE USED IN SELECTING THE "BEST" TYPE OF LEFT TURN PHASING.

Chapters 3 and 5 presented recommended approaches for evaluating the relative safety and the operating characteristics of different types of left turn phasing. As stated in the preceding chapter, "The ultimate goal is to combine information on relative safety and operating characteristics to develop warrants or other means of deciding when different types of left turn phasing should be used." Once the relative safety and the operating characteristics have been quantified then some criteria for "optimizing" intersection operation are needed. Which measures of effectiveness are important and should be used? What is an appropriate trade-off between safety and operational factors?

It is recommended that criteria be developed which are as comprehensive as possible and which incorporate as many of the measures of effectiveness of intersection operation as is practical. An approach which has been used previously by one member of the research team is to quantify as many operational factors as possible in terms of dollar cost. Delay for example, is translated into a dollar cost based upon the value of the road user's time. Fuel consumption, as another example, is translated into a dollar cost based upon the price of fuel. The principal advantage of this approach is that a wide variety of different operational factors can be compared on a common basis. This makes it easier to do an overall comparison of the various impacts of different types of left turn phasing.

The following costs are recommended for inclusion.

1. & 2. Vehicle Operating Costs.

   (Vehicle Operating Cost is comprised of one major component, fuel consumption, and several other factors including oil consumption, tire wear, maintenance, and depreciation. For convenience, Vehicle Operating Cost is described by two components, Fuel Costs and Other Vehicle Operating Cost.)

3. Delay Costs (value of road user's time)

4. Air Pollution Costs

Accident Costs could also be included in the above list. However, the research team does not recommend that it be included. There is a reluctance in the highway community to put a price on an accident, injury, or fatality. We believe that the traffic engineer should be given information on the relative costs and expected safety performance of different types of left turn phasing and then be allowed to make a judgement on the tradeoffs, if any, involved.

Each of the costs listed above can be calculated using output statistics from NETSIM. As will be indicated in the Work Plan, software should be developed to automatically determine these costs using NETSIM output statistics.

In addition to dollar cost and safety performance, one other factor should be considered in selection of the type of left turn phasing. That factor is whether or not any intolerable operating conditions would exist with any of the types of left turn phasing. Four examples of intolerable conditions are:

1. ≥ 35 seconds of average left-turn delay
2. ≥ 73 seconds of ninety-percentile left-turn delay
3. five percent of left turners being delayed more than two cycles.
4. four left turners in one hour being delayed more than two cycles.

These represent conditions that would be unacceptable to the motorist. These four conditions were used in developing the "Guidelines for use of Left-Turn Lanes and Signal Phases" (11)..

In summary, the approach to be used in selecting the "best" type of left turn phasing for a particular intersection would be as follows.

- NETSIM would be used to generate information on intersection operation and costs (fuel consumption cost, other vehicle operating cost, delay cost, and air pollution cost) for each type of left turn phasing.
- Expected safety performance would be calculated for each type of left turn phasing.
- Any type of left turn phasing resulting in intolerable conditions would be eliminated from consideration.
- The traffic engineer would review the relative costs and safety performance of the remaining types of left turn phasing and select one for implementation.

CHAPTER 7 - WORK PLAN

This chapter presents a proposed work plan for the future research project as well as an estimated cost for conducting the work. The work plan is designed to meet the goal of developing a warrant or guideline for use of left turn phasing. The work plan is presented in a format and in a level of detail suitable for inclusion in a request for proposals.

WORK PLAN

Note: The work plan presented below is based upon the assumption that NETSIM will be validated and that it will be found suitable for use before the work plan is initiated.

Task 1. Take accident statistics presented in this report and put them in a form that can be easily used by the traffic engineer to compare relative safety of different types of left turn phasing. This might, for example, be a simple formula for predicting the annual number of left turn accidents based upon a 24-hour left turn volume. As an alternative, it might be a simple formula based upon both the 24-hour left turn volume and the 24-hour opposing volume.

Task 2. Modify the microcomputer version of NETSIM or design a post-processor so that it will generate output statistics on : 1) vehicle operating costs; 2) fuel costs; 3) delay costs; and 4) air pollution costs. The new programming should provide user ability to select the unit costs (price/gallon for fuel, for example) for each item as well as have default values. The documentation should explain how the user can update unit costs as they change with time.

Task 3. Prepare documentation and instructions for use of NETSIM to evaluate different types of left turn signal phasing at individual intersections. The documentation and instructions shall be prepared such that:

a) it is "packaged" in a way that traffic engineers can easily use it to evaluate different types of phasing (i.e., a "cookbook" of instructions);

b) various intersection characteristics can be considered;

c) NETSIM will evaluate different types of left turn phasing in one run of the program;

d) it explains how to interpret the output for making a choice in the type of left turn phasing.

Task 4. Prepare guidelines on how to use the results of the safety evaluation in Task 1 and the NETSIM output in Task 3 to select the "best" type of left turn phasing. The guidelines shall be developed to rely primarily on : relative safety (Task 1); operating costs (Task 2); and identification of any signal operations that would result in intolerable conditions (such as unacceptable delay for left turning vehicles). To provide the traffic engineer with a basis for comparing accidents to operating costs, the guidelines shall present accepted values for the cost of an accident.

Task 5. Field test the application of the new NETSIM package at a minimum of three intersections. If available, conduct before and after field tests at a minimum of three intersections which are being converted from one type of left turn phasing to another. Use NETSIM output statistics which can easily be collected in the field to demonstrate the model's ability or inability to show relative differences in operation for different types of left turn phasing. If only three intersections are used, at least 6 hours of field data should be collected at each site. A larger number of intersections would provide greater variety in types of left turn phasing. If ten intersections are identified, as few as two hours of field data could be collected at each.

Task 6. Demonstrate use of: 1) the new NETSIM package, its documentation, its instructions (Task 3); and 2) the guidelines (Task 4) for a sample intersection.

ESTIMATED COST

The work plan does not require additional data collection for signalized intersections. Estimated cost, broken down by task, is presented below.

Task 1	$ 2,000
Task 2	15,000
Task 3	6,000
Task 4	4,000
Task 5	6,000
Task 6	2,000
TOTAL	$35,000

The estimated time required to do tasks 1 through 6 is ten months.

CHAPTER 8 - RECOMMENDATIONS FOR FURTHER STUDY

Two recommendations are made for further study.

First, it is strongly recommended that a research effort be conducted to evaluate the NETSIM model to determine if it is a suitable candidate to serve the role originally intended for the TEXAS model. Validation testing should be conducted to determine if the NETSIM model can replicate traffic characteristics as they exist in the field, particularly for left turning vehicles under different types of left turn phasing. If NETSIM can successfully pass validation testing, then it can be used to evaluate the operational characteristics of different types of left turn phasing. Additional information on the role that NETSIM could play in developing left turn signal warrants is presented in Chapter 7.

Second, the future research project that was designed in this study must be undertaken so that warrants or guidelines for selecting the type of left turn phasing can be developed. The detailed recommendations on the scope of work are presented in Chapter 7.

APPENDIX A

GLOSSARY

Definition of types of Left Turn Signal Phasing

Permissive Left Turn -	Vehicles are allowed to make a left turn on a circular green indication after they yield to oncoming traffic (sometimes called a permitted left turn)
Exclusive Left Turn -	Vehicles are allowed to make a left turn only on a green arrow indication (sometimes called a protected left turn). The exclusive portion of the signal cycle (the green arrow) may either precede (lead) or follow (lag) the permissive (circular green) portion of the cycle.
Exclusive/Permissive Left Turn -	Vehicles are allowed to make a left turn either on a green arrow indication or on a circular green indication after yielding to oncoming traffic (sometimes called protected/permitted left turn). The exclusive portion of the signal cycle (the green arrow) may either precede (lead) or follow (lag) the permissive (circular green) portion of the cycle.
Split Phasing -	This is a specialized form of exclusive left turn phasing. With split phasing one approach of an intersection is directed to proceed, including left turn drivers on an exclusive left turn. When this approach is stopped the opposing approach is directed to proceed, including left turn drivers on an exclusive left turn.

APPENDIX B.

SOURCES OF DATA AS PROVIDED BY ADOT

TABLE B-1

SOURCES OF DATA AS PROVIDED BY ADOT

Source number	Description
1.	Inventory of all Signalized Intersection Locations
2.	Signalized Intersection Accident Listing (A) 1982, 1983, 1984
3.	Signalized Intersection Accident Listing (B) 1982, 1983, 1984
4.	Non-Signalized Intersection Accident Listing (A) 1982, 1983, 1984
5.	Non-Signalized Intersection Accident Listing (B) 1982, 1983, 1984
6.	Accident Data Printout (run 12-04-86) for 01-01-83 to 12-31-85 (All intersections on the state highway system which had any accidents in this 3 year period.)
7.	Signals Inventory for 164 Intersections
8.	Signal ADOT Maintained
9.	Signalized Intersection Tabulation, Left Turn Phasing 22 Sept. 86, Intersections Without Left Turn Phasing
10.	Signalized Intersection Tabulation, Left Turn Phasing, Intersections with Left Turn Phasing.
11.	Traffic Accident Listing, All Accidents from 01/01/85 through 12/31/85 (run on 6/27/86)
12.	Signalized Intersection Inventory with code numbers 20 through 8000 (Traffic Signal Layout Diagrams)
13.	Statewide Speed Data (Printed dated 12/03/86)
14.	Turning Movement Volume Survey Summary Forms (various dates)
15.	Subdistrict Map (3 pages)

Xerox copies of the first or cover sheet of each data item are included on the following pages.

ISTRICT 1 | SUB-DISTRICT "A" Signals | 11-07-86

* NEW INTERSECTIONS

OCATION	CODE	UNIT	DEVICE # FROM	TO	MILEPOST	JURISDICTIONAL MAINT	PWR. CO.	TURN ON DATE	NO. OF FEATURES	GEOGRAPHIC LOCATION
10 & Litchfield Road	20	2010A	2011	2029	128.69	ADOT	APS	08/08/78	16	Mrcpa Cnty
10 & Dysart Road	40	2030A	2031	2049	129.70	ADOT	APS	08/08/78	16	Mrcpa Cnty
10 & 99th Avenue	120	2100A	2101	2129	133.70	ADOT	SRP	05/17/84	18	Mrcpa Cnty
10 & 91st Avenue	140	0420A	0421	0449	134.68	ADOT	SRP	06/21/85	20	Tolleson
10 & 83rd Avenue	160	0990A	0991	1019	135.67	ADOT	SRP	06/20/85	20	Phoenix
10 & 75th Avenue	180	1020A	1021	1049	136.69	ADOT	SRP	06/24/85	20	Phoenix
10 & 67th Avenue	200	1110A	1111	1139	137.67	ADOT	SRP	06/21/85	20	Phoenix
10 & 59th Avenue	220	1260A	1261	1289	138.30	ADOT	SRP	06/24/85	20	Phoenix
10 & 51st Avenue	221	4820A	4821	4839	139.05	ADOT	SRP	02/28/86	14	Phoenix
10 & 43rd Avenue	222	4840A	4841	4869	139.80	ADOT	SRP	02/28/86	16	Phoenix
10 & 35th Avenue	223	4880A	4881	4899	140.55	ADOT	APS	02/28/86	14	Phoenix
10 & 27th Avenue	224	4900A	4901	4929	141.30	ADOT	APS	02/28/86	11	Phoenix
10 & 24th Street	260	0060A	0061	0089	149.62	ADOT	APS	11/09/71	13	Phoenix
10 & 40th Street	280	0090A	0091	0119	152.10	ADOT	SRP	11/29/65	16	Phoenix
10 (52nd St) & Broadway	300				153.30	TEMPE	SRP	10/07/82		Tempe
10 & Baseline Road	320				155.64	TEMPE	SRP	04/11/67		Tempe
10 & Elliot Road	340	0180A	0181	0199	157.74	ADOT	SRP	05/19/83	11	Mrcpa Cnty
10 & Warner Road	* 345	0210A	0211	0239	158.60	ADOT	SRP	04/21/86	19	Mrcpa Cnty
10 & Ray Road	* 350	0240A	0241	0269	159.60	ADOT	SRP	09/18/86	21	Mrcpa Cnty

Source Number 1

Source Number 2

SIGNALIZED INTERSECTION ACCIDENT LISTING (A)

#	D	Route	Intersecting Street	MP	Jurisdiction	Sig-nal?	ADOT Maint?	ANGLES 82	ANGLES 83	ANGLES 84	ANGLES Tot	LEFT TURNS 82	LEFT TURNS 83	LEFT TURNS 84	LEFT TURNS Tot
1	1	I 0017 SBFR	ADAMS STREET	199.69	PHOENIX	Y	Y	9	9	9	27	1	0	0	1
2	1	U 0060	76TH STREET	188.98	MESA	Y	Y	10	14	3	27	1	1	1	3
3	1	I 0017 SBFR	NORTHERN AVENUE	206.90	PHOENIX	Y	Y	7	5	10	22	7	11	2	20
4	1	I 0017 NBFR	JEFFERSON STREET	199.53	PHOENIX	Y	Y	8	2	9	19	0	0	0	0
5	1	U 0060	107TH AVENUE #0	147.12	MARICOPA CO.	Y	Y	4	6	8	18	0	3	0	3
6	3	SB0008	22ND STREET	2.87	YUMA	Y	Y	12	4	1	17	4	4	2	10
7	4	SB0040	STEVES BOULEVARD	199.25	FLAGSTAFF	Y	Y	4	6	7	17	1	0	1	2
8	1	U 0060	67TH AVENUE	153.35	GLENDALE	Y	Y	7	6	4	17	4	7	4	15
9	1	S 0087	WARNER ROAD	168.71	CHANDLER	Y	Y	8	6	1	15	1	3	5	9
10	3	U 0095	1ST AVENUE	23.62	YUMA	Y	Y	4	5	6	15	0	5	5	10
11	1	I 0017 SBFR	McDOWELL ROAD	200.88	PHOENIX	Y	Y	7	3	4	14	4	2	4	10
12	1	I 0010157A	ELLIOT ROAD	157.74	MARICOPA CO.	Y	Y	7	3	3	13	2	6	2	10
13	1	I 0017 SBFR	INDIAN SCHOOL ROAD	202.90	PHOENIX	Y	Y	5	1	7	13	20	23	26	69
14	1	I 0017 SBFR	CAMELBACK ROAD	203.90	PHOENIX	Y	Y	2	5	6	13	6	10	15	31
15	1	I 0017 SBFR	PEORIA AVENUE	208.93	PHOENIX	Y	Y	4	1	8	13	0	3	3	6
16	1	I 0017 NBFR	7TH AVENUE	196.94	PHOENIX	Y	Y	3	4	5	12	2	0	0	2
17	1	I 0017 NBFR	CAMELBACK ROAD	203.90	PHOENIX	Y	Y	0	9	3	12	6	4	5	15
18	3	U 0095	24TH STREET	20.89	YUMA	Y	Y	7	3	2	12	2	0	2	4
19	1	I 0017 NBFR	THOMAS ROAD	201.93	PHOENIX	Y	Y	2	6	3	11	1	1	0	2
20	1	I 0017 SBFR	CACTUS ROAD	209.94	PHOENIX	Y	Y	3	4	4	11	3	2	0	5
21	1	S 0360003A	RURAL ROAD	2.41	TEMPE	Y	Y	7	3	1	11	2	2	1	5
22	4	SB0040	BEAVER STREET	196.24	FLAGSTAFF	Y	Y	2	3	6	11	2	0	0	2
23	1	I 0017 SBFR	JEFFERSON STREET	199.53	PHOENIX	Y	Y	4	2	4	10	0	0	0	0
24	1	I 0017 SBFR	THOMAS ROAD	201.93	PHOENIX	Y	Y	0	4	6	10	0	2	1	3
25	1	U 0060	99TH AVENUE #0	148.20	MARICOPA CO.	Y	Y	4	2	4	10	1	0	2	3
26	1	U 0060	55TH AVENUE	155.45	GLENDALE	Y	Y	5	3	2	10	6	2	2	10
27	1	U 0060	51ST AVENUE	156.18	GLENDALE	Y	Y	5	5	0	10	1	3	6	10
28	1	U 0060	SIGNAL BUTTE ROAD	193.01	MARICOPA CO.	Y	Y	5	1	4	10	2	2	1	5
29	3	U 0095	AVENUE A	22.88	YUMA	Y	Y	6	3	1	10	2	2	3	7
30	1	I 0017 SBFR	VAN BUREN STREET	199.82	PHOENIX	Y	Y	4	4	1	9	0	0	0	0
31	1	I 0017 SBFR	DUNLAP AVENUE	207.96	PHOENIX	Y	Y	4	0	5	9	5	7	10	22
32	1	S 0085	91ST AVENUE	183.86	MARICOPA CO.	Y	Y	3	3	3	9	1	4	0	5
33	1	S 0087	CHANDLER BOULEVARD	166.73	CHANDLER	Y	Y	1	2	6	9	5	5	4	14
34	3	SB0008	U 0095	2.11	YUMA	Y	Y	3	4	2	9	8	9	7	24
35	3	SB0008	32ND STREET	4.23	YUMA	Y	Y	3	3	3	9	0	3	5	8
36	4	SB0040	SAN FRANCISCO STREET	196.37	FLAGSTAFF	Y	Y	3	1	5	9	4	1	2	7
37	1	U 0060	61ST AVENUE	154.39	GLENDALE	Y	Y	3	4	2	9	1	0	0	1
38	1	U 0060	ELLSWORTH ROAD	191.00	MARICOPA CO.	Y	Y	1	1	7	9	1	1	5	7
39	2	U 0089	MAGEE ROAD	75.89	PIMA COUNTY	Y	Y	1	4	4	9	2	3	1	6
40	4	UA0089	RIORDAN ROAD	403.17	FLAGSTAFF	Y	Y	2	4	3	9	0	0	4	4

Source Number 3

SIGNALIZED INTERSECTION ACCIDENT LISTING (B)

#	D	Route	Intersecting Street	MP	Jurisdiction	Signal?	ADOT Maint?	LEFT TURNS 82	LEFT TURNS 83	LEFT TURNS 84	LEFT TURNS Tot	ANGLES 82	ANGLES 83	ANGLES 84	ANGLES Tot
1	1	I 0017 SBFR	INDIAN SCHOOL ROAD	202.90	PHOENIX	Y	Y	20	23	26	69	5	1	7	13
2	1	U 0060	43RD AVENUE	157.61	PHOENIX	Y	N	21	19	20	60	4	5	4	13
3	1	U 0060	24TH STREET	166.24	PHOENIX	Y	N	17	15	21	53	8	4	12	24
4	1	I 0010151A	40TH STREET	152.10	PHOENIX	Y	Y	14	16	18	48	1	1	2	4
5	1	U 0060	44TH STREET	168.72	PHOENIX	Y	N	12	11	21	44	5	6	9	20
6	2	U 0089	PRINCE ROAD	70.30	TUCSON	Y	N	14	12	9	35	7	6	3	16
7	1	U 0060	35TH AVENUE	159.01	PHOENIX	Y	N	11	14	8	33	3	2	2	7
8	1	I 0017 SBFR	CAMELBACK ROAD	203.90	PHOENIX	Y	Y	6	10	15	31	2	5	6	13
9	1	I 0017 NBFR	DUNLAP AVENUE	207.96	PHOENIX	Y	Y	9	5	16	30	1	2	1	4
10	1	U 0089	S 0086	63.42	TUCSON	Y	N	10	9	11	30	6	1	8	15
11	2	U 0089	VALENCIA ROAD	60.41	TUCSON	Y	N	6	8	15	29	1	1	4	6
12	1	U 0060	27TH AVENUE	160.31	PHOENIX	Y	N	10	11	7	28	6	9	6	21
13	1	S 0085	35TH AVENUE	190.88	PHOENIX	Y	N	6	4	17	27	8	2	4	14
14	2	U 0089	22ND STREET	65.45	TUCSON	Y	N	6	8	12	26	4	2	7	13
15	1	I 0017 NBFR	INDIAN SCHOOL ROAD	202.90	PHOENIX	Y	Y	7	9	10	26	2	1	5	8
16	1	U 0060	40TH STREET	168.25	PHOENIX	Y	N	17	3	5	25	10	8	7	25
17	1	U 0060	32ND STREET	167.23	PHOENIX	Y	N	7	8	10	25	4	7	10	21
18	2	U 0089	INA ROAD	74.85	PIMA COUNTY	Y	Y	14	7	4	25	2	3	2	7
19	1	U 0060	20TH STREET	165.63	PHOENIX	Y	N	3	8	13	24	10	5	8	23
20	2	U 0089	GRANT ROAD	68.77	TUCSON	Y	N	3	12	9	24	5	3	1	9
21	3	SB0008	U 0095	2.11	YUMA	Y	Y	8	9	7	24	3	4	2	9
22	2	S 0086	12TH AVENUE	171.85	TUCSON	Y	N	10	8	5	23	5	2	5	12
23	1	I 0017 SBFR	DUNLAP AVENUE	207.96	PHOENIX	Y	Y	5	7	10	22	4	0	5	9
24	1	U 0060	PAPAGO PARKWAY	170.51	PHOENIX	Y	N	7	5	9	21	2	0	0	2
25	2	U 0089	SPEEDWAY BOULEVARD	67.47	TUCSON	Y	N	5	6	10	21	7	11	9	27
26	1	U 0060	APACHE BOULEVARD	173.29	TEMPE	Y	N	9	2	10	21	1	1	1	[illegible]
27	1	S 0360007A	ALMA SCHOOL ROAD	6.41	MESA	Y	N	5	9	7	21	2	0	4	[illegible]
28	1	U 0060	75TH AVENUE	151.95	MARICOPA CO.	Y	Y	2	8	11	21	1	4	2	[illegible]
29	1	U 0060	McALLISTER AVENUE	173.91	TEMPE	Y	N	9	4	7	20	1	0	2	[illegible]
30	1	U 0060	7TH STREET	164.24	PHOENIX	Y	N	8	8	4	20	7	9	7	23
31	1	I 0017 SBFR	NORTHERN AVENUE	206.90	PHOENIX	Y	Y	7	11	2	20	7	5	10	22
32	1	I 0017 NBFR	NORTHERN AVENUE	206.90	PHOENIX	Y	Y	7	10	3	20	1	4	1	6
33	1	U 0060	COLLEGE AVENUE	173.66	TEMPE	Y	Y	6	6	8	20	4	2	1	7
34	1	S 0087	BROWN ROAD	175.62	MESA	Y	N	2	9	8	19	4	5	4	13
35	2	U 0089	FT. LOWELL ROAD	69.78	TUCSON	Y	N	11	6	2	19	2	6	1	9
36	1	S 0087	RAY ROAD	167.69	CHANDLER	Y	Y	5	6	8	19	0	2	3	5
37	3	SB0008	8TH STREET	1.12	YUMA	Y	Y	7	7	4	18	4	2	2	8
38	2	S 0086	MISSION ROAD	170.35	TUCSON	Y	N	9	3	6	18	0	0	4	4
39	2	S 0090	SS0090 (EAST GATE)	317.17	SIERRA VISTA	Y	Y	3	5	10	18	4	0	0	4
40	1	S 0087	UNIVERSITY DRIVE	174.76	MESA	Y	N	5	4	9	18	3	0	2	5
41	1	S 0360007C	ALMA SCHOOL ROAD	6.41	MESA	Y	N	5	7	5	17	3	2	1	6
42	1	U 0060	POWER ROAD/BUSH HIGHWAY	188.00	MESA	Y	N	5	3	8	16	2	0	5	7
43	1	I 0017 SBFR	GLENDALE AVENUE	205.91	PHOENIX	Y	Y	6	6	4	16	0	5	2	7
44	2	U 0089	44TH STREET	63.91	TUCSON	Y	N	2	5	8	15	1	0	2	3
45	1	I 0017 NBFR	CAMELBACK ROAD	203.90	PHOENIX	Y	Y	6	4	5	15	0	9	3	12
46	1	U 0060	67TH AVENUE	153.35	GLENDALE	Y	Y	4	7	4	15	7	6	4	17
47	1	U 0060	GREENFIELD ROAD	185.01	MESA	Y	N	2	7	6	15	2	5	5	12
48	3	SB0008	24TH STREET	3.12	YUMA	Y	Y	3	8	3	14	0	0	1	1
49	4	SB0040	ARROWHEAD DRIVE	198.22	FLAGSTAFF	Y	Y	4	5	5	14	1	1	1	3
50	1	S 0360008J	COUNTRY CLUB DRIVE	7.39	MESA	Y	N	7	6	1	14	0	0	2	2
51	1	S 0087	CHANDLER BOULEVARD	166.73	CHANDLER	Y	Y	5	5	4	14	1	2	6	9
52	1	S 0360008G	COUNTRY CLUB DRIVE	7.39	MESA	Y	N	7	6	1	14	0	0	3	3
53	2	U 0089	RUDASILL ROAD	73.35	PIMA COUNTY	Y	Y	6	4	3	13	0	1	0	1
54	1	U 0060	52ND STREET	169.71	PHOENIX	Y	N	5	3	5	13	0	0	0	0
55	1	S 0085	43RD AVENUE	189.86	PHOENIX	Y	N	2	6	5	13	1	2	7	10
56	1	S 0143	WASHINGTON STREET	2.73	PHOENIX	Y	N	1	4	8	13	2	3	3	8
57	2	I 0010262C	PARK AVENUE	261.74	TUCSON	Y	N	8	4	0	12	1	0	0	1
58	1	I 0017 NBFR	16TH STREET	195.05	PHOENIX	Y	Y	4	3	5	12	1	0	0	1
59	2	U 0089	LIMBERLOST DRIVE	71.05	TUCSON	Y	N	6	3	3	12	0	1	2	3
60	2	S 0086	KINNEY ROAD	166.22	PIMA COUNTY	Y	Y	1	5	6	12	0	2	0	2
61	1	U 0060	91ST AVENUE	149.25	PEORIA	Y	Y	2	5	5	12	0	0	1	1
62	1	U 0060	PEORIA AVENUE #1	150.50	PEORIA	Y	Y	7	3	2	12	0	2	1	3
63	1	S 0085	19TH AVENUE	192.84	PHOENIX	Y	N	5	4	3	12	5	4	2	11
64	1	S 0087	8TH AVENUE	173.28	MESA	Y	N	2	2	8	12	2	3	4	9
65	1	S 0360002A	MILL AVENUE	1.65	TEMPE	Y	Y	3	5	4	12	6	1	0	7
66	1	S 0360002C	MILL AVENUE	1.65	TEMPE	Y	Y	2	3	7	12	2	0	2	4
67	3	S 0095	LONDON BRIDGE ROAD	182.48	LK HAV CITY	Y	Y	3	4	4	11	0	1	1	2
68	1	U 0060	6TH STREET	172.77	TEMPE	Y	N	3	5	3	11	0	1	2	3
69	3	UA0089	COTTONWOOD ST./MAIN ST.	353.09	COTTONWOOD	Y	Y	5	3	3	11	1	0	1	2
70	2	I 0010 EBFR	CONGRESS STREET	258.36	TUCSON	Y	N	2	3	6	11	1	5	22	28

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U 60 – Papago   U 60 – Apache

NON-SIGNALIZED INTERSECTION ACCIDENT LISTING (A)

#	D	Route	Intersecting Street	MP	Jurisdiction	Signal?	ADOT Maint?	ANGLES 82	ANGLES 83	ANGLES 84	ANGLES Tot	LEFT TURNS 82	LEFT TURNS 83	LEFT TURNS 84	LEFT TURNS Tot
1	1	U 0060	MERIDIAN DRIVE	193.99	APACHE JCT.	N	N	10	14	12	36	2	0	0	2
2	1	U 0060 WB	1ST STREET	172.41	TEMPE	N	N	12	3	8	23	12	2	2	16
3	1	U 0060	74TH STREET	188.72	MESA	N	N	2	8	10	20	0	1	0	1
4	1	I 0017 NBFR	BEARDSLEY ROAD	214.96	PHOENIX	N	N	6	7	7	20	0	0	1	1
5	1	S 0085	83RD AVENUE	184.84	MARICOPA CO.	N	N	3	9	7	19	0	0	1	1
6	1	S 0087	PECOS ROAD	165.70	MARICOPA CO.	N	N	5	6	5	16	2	3	3	8
7	1	U 0060	80TH STREET	189.49	MARICOPA CO.	N	N	5	6	5	16	0	1	1	2
8	1	S 0087	SAGUARO LAKE ROAD	199.11	MARICOPA CO.	N	N	6	5	4	15	0	0	0	0
9	1	U 0060	96TH STREET	191.49	MARICOPA CO.	N	N	6	7	2	15	0	0	1	1
10	1	S 0085	75TH AVENUE	185.86	MARICOPA CO.	N	N	7	4	3	14	1	2	0	3
11	1	U 0060	IDAHO ROAD	196.04	APACHE JCT.	N	N	4	4	6	14	0	0	0	0
12	1	U 0060	5TH STREET	164.10	PHOENIX	N	N	4	7	2	13	0	0	0	0
13	1	U 0060	SANTA FE DRIVE	144.82	EL MIRAGE	N	N	2	3	7	12	1	0	1	2
14	1	U 0060	WELDON AVENUE	159.53	PHOENIX	N	N	6	2	4	12	1	0	0	1

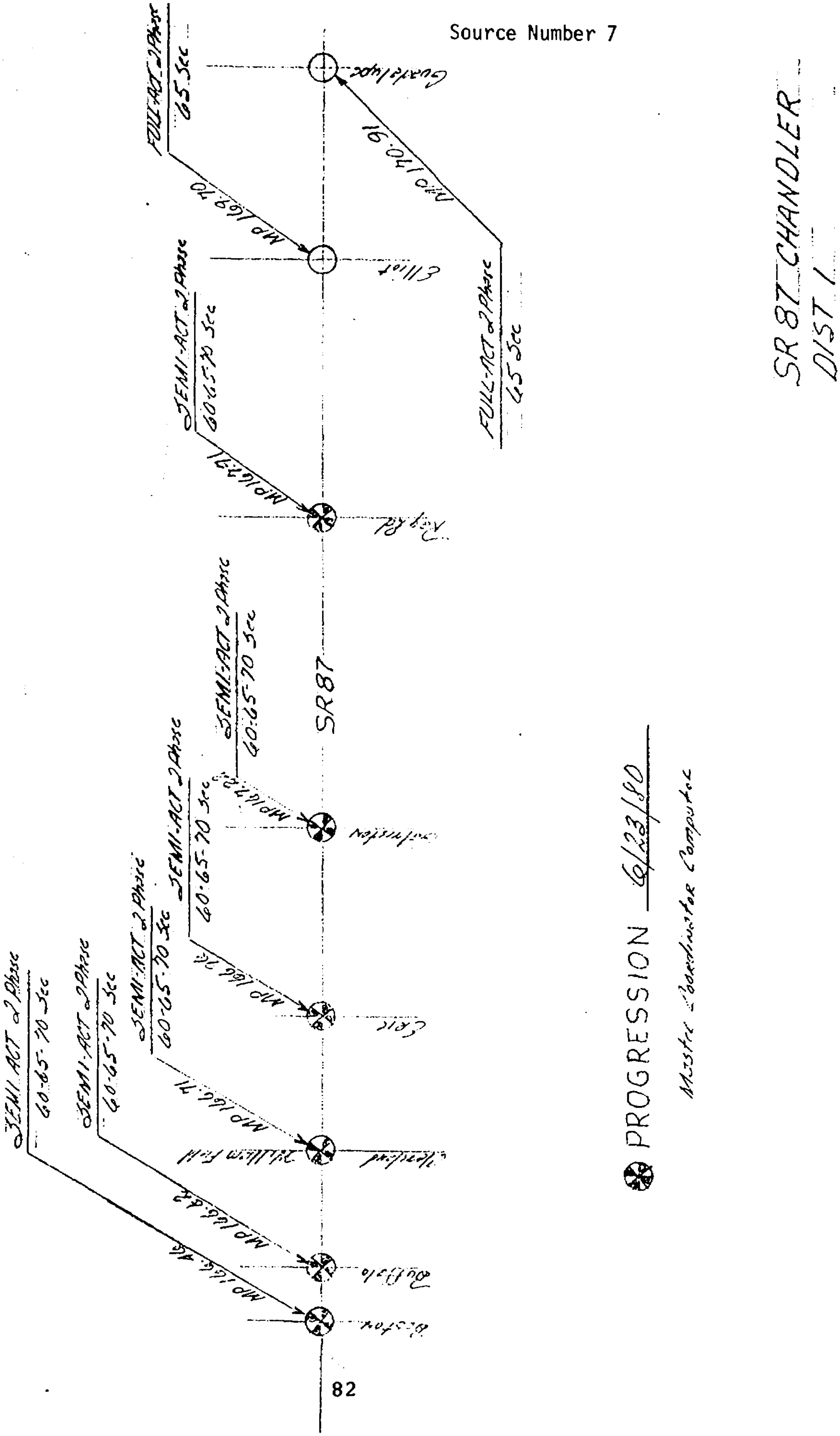
NON-SIGNALIZED INTERSECTION ACCIDENT LISTING (B)

#	D	Route	Intersecting Street	MP	Jurisdiction	Signal?	ADOT Maint?	LEFT TURNS 82	83	84	Tot	ANGLES 82	83	84	Tot
1	1	U 0060 WB	1ST STREET	172.41	TEMPE	N	N	12	2	2	16	12	3	8	23
2	2	U 0089	STONE AVENUE #2	67.89	TUCSON	N	N	4	3	6	13	0	0	4	4
3	1	U 0060	3RD STREET	172.55	TEMPE	N	N	1	7	4	12	1	3	1	5

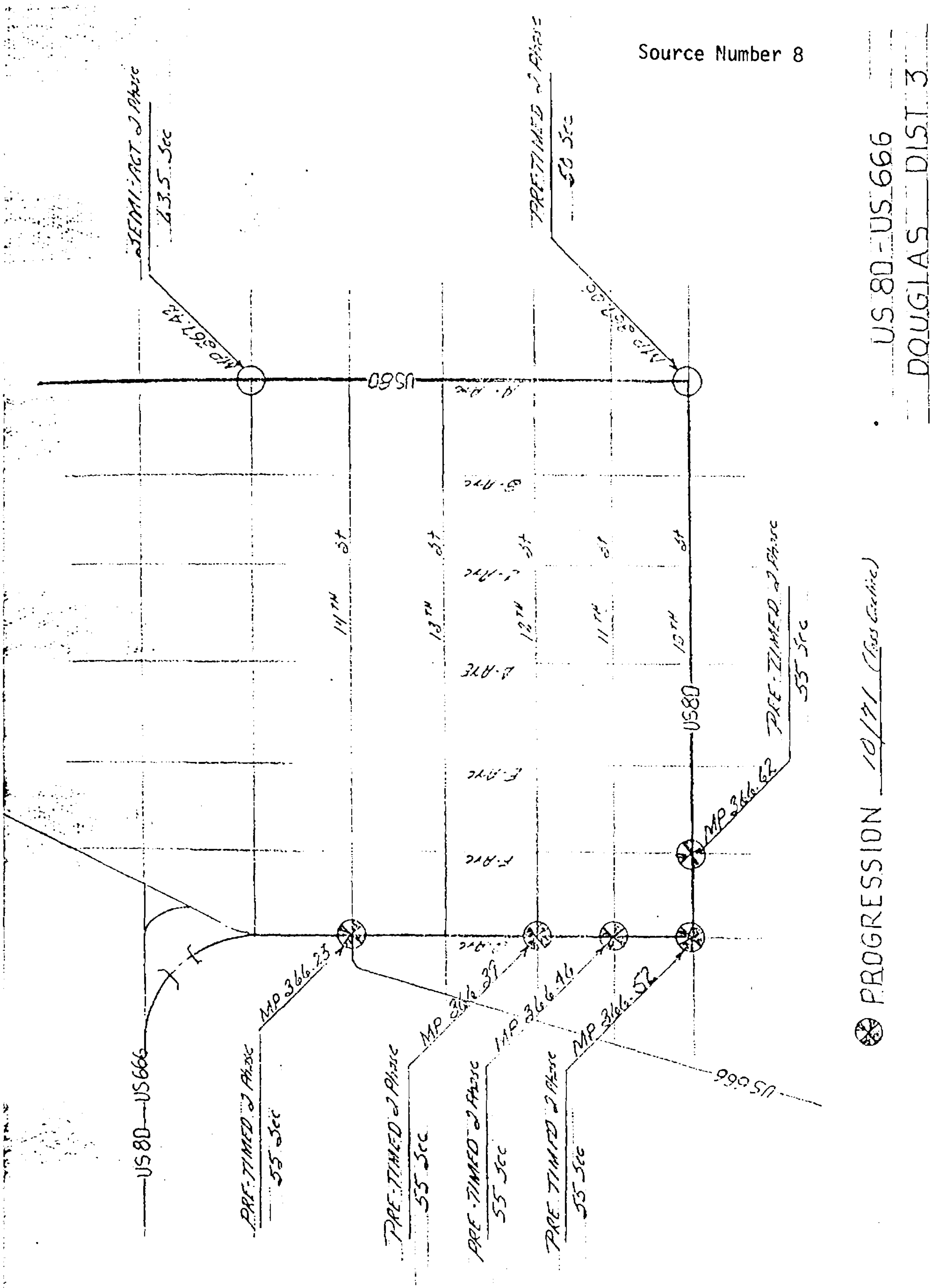
Source Number 6

ON STREET	X ##	X INTERSECT ##STREET	X ###		RATE A/MV	ANGLE	PEDS	LEFT TURN	REAR END	SIDE SWIPE	TOTAL	NIGHT ANGLE	NIGHT TOTAL	CLASS	PREDOMINANT TYPE	DI	APPROA VOLUME
S 0085		0723 36TH	DR		0.25	1	0	0	3	0	7	0	0	M-L	REAR-END	E	26,000
S 0085		0723 67TH	AV		0.63	5	0	5	4	0	14	1	2	M-M	ANGLE	W	20,300
S 0085		0723 27TH	AV		1.60	17	0	16	13	2	56	3	11	M-M	ANGLE	E	31,900
S 0085		0723 17TH	AV		0.88	8	0	2	1	1	16	1	3	M-M	ANGLE	E	16,600
S 0085		0723 37TH	DR		0.04	0	0	0	1	0	1	0	1	M-L	REAR-END	W	26,000
S 0085		0723 28TH	AV		0.23	3	1	0	1	0	11	0	2	M-L	SINGLE VEHICLE	S	30,000
S 0085		0723 18TH	AV	1	0.34	0	0	1	1	0	5	0	1	M-L	SINGLE VEHICLE	E	16,200
S 0085		0723 18TH	AV	2	0.62	0	0	0	5	2	11	0	3	M-M	REAR-END	W	16,200
S 0085		0723 59TH	AV		0.91	5	1	4	8	0	23	2	5	M-M	REAR-END	E	23,198
S 0085		0723 19TH	AV		1.85	14	4	17	12	0	60	6	16	M-M	LEFT TURN	E	29,200
S 0085		0723 39TH	AV	1	0.67	3	0	0	12	1	17	0	2	M-C	REAR-END	E	26,000
S 0085		0723 29TH	AV	1	0.09	2	0	1	0	0	3	0	1	M-C	ANGLE	W	30,000
S 0085		0723 39TH	AV	2	0.00	0	0	0	0	0	0	0	0	M-C	-	-	26,000
S 0085		0731 91ST	AV		1.10	8	0	5	4	0	21	3	6	M-L	ANGLE	E	17,400
S 0085	0	0723 WASHINGTON	ST			1	0	0	0	0	1	1	1	-	ANGLE	S	
S 0085	0	0723 16TH	AV		0.65	1	0	0	0	0	2	0	0	-	ANGLE	W	2,800
SS0085		0700 BASELINE	RD		0.66	4	0	0	0	0	4	2	2	-	ANGLE	W	5,500
SS0085		0700 SOUTHERN	AV		1.52	1	0	0	0	0	1	1	1	-	ANGLE	W	600
SS0085		0700 BROADWAY	RD		3.65	1	0	0	0	0	1	1	1	-	ANGLE	N	250
S 0087		U 0060			0.89	9	4	9	19	1	49	4	15	-	REAR-END	E	50,500
S 0087		S 0360008G				11	0	4	14	0	39	3	12	-	REAR-END	N	
S 0087		S 0360009J				2	0	9	11	0	29	0	8	-	REAR-END	N	
S 0087		S 0587			1.40	4	0	0	0	0	4	1	1	-	ANGLE	S	2,600
S 0087		0700 SAGUARO LAKE	RD		2.09	10	0	0	1	0	18	0	2	-	ANGLE	W	7,847
S 0087		0700 CAMPBELL	RD			1	0	0	0	0	1	0	0	-	ANGLE	W	

Source Number 7



Source Number 8



INTERSECTIONS WITHOUT LEFT TURN PHASING

	LOCATION	WIDTH OF APPR.	SPD. LMT.	TURN ON DATE	ACCIDENT HISTORY 7/1/82 - 6/30/85	
ROUTE/M.P.	*US 60/ MP 144.40	E 12 FT.	50			
CROSS ST.	*FACTORY ST.	W 12 FT.			WEST	1
COMMUNITY	*EL MIRAGE				EAST	0
ROUTE/M.P.	*US 60/ MP 149.25	E 24 FT.	45			
CROSS ST.	*91ST AVE.	W 24 FT.			WEST	3
COMMUNITY	*PEORIA				EAST	6
ROUTE/M.P.	*US 60/ MP 150.20	E 24 FT.	35			
CROSS ST.	*85TH AVE.	W 24 FT.			WEST	2
COMMUNITY	*PEORIA				EAST	0
ROUTE/M.P.	*US 60/ MP 150.45	E 30 FT.	35			
CROSS ST.	*PEORIA AVE.	W 30 FT.			WEST	3
COMMUNITY	*PEORIA				EAST	6
ROUTE/M.P.	*US 60/ MP 159.36	E 24 FT.	45			
CROSS ST.	*33RD AVE.	W 24 FT.			WEST	0
COMMUNITY	*PHOENIX				EAST	8
ROUTE/M.P.	*US 60/ MP 159.72	E 24 FT.	45			
CROSS ST.	*OSBORN RD.	W 24 FT.			WEST	0
COMMUNITY	*PHOENIX				EAST	11
ROUTE/M.P.	*US 60/ MP 163.36	E 12 FT.	25			
CROSS ST.	*5TH AVE.	W 12 FT.			WEST	0
COMMUNITY	*PHOENIX				EAST	1
ROUTE/M.P.	*US 60/ MP 163.50	E 12 FT.	25			
CROSS ST.	*3RD AVE.	W 12 FT.			WEST	0
COMMUNITY	*PHOENIX				EAST	1
ROUTE/M.P.	*US 60/ MP 163.58	E 12 FT.	25			
CROSS ST.	*2ND AVE.	W 12 FT.			WEST	0
COMMUNITY	*PHOENIX				EAST	1
ROUTE/M.P.	*US 60/ MP 163.65	0 FT.	25			
CROSS ST.	*1ST AVE.	0 FT.			WEST	2
COMMUNITY	*PHOENIX				EAST	2
ROUTE/M.P.	*US 60/ MP 163.72	0 FT.	25			
CROSS ST.	*CENTRAL AVE.	0 FT.			WEST	0
COMMUNITY	*PHOENIX				EAST	0
ROUTE/M.P.	*US 60/ MP 163.80	E 12 FT.	25			
CROSS ST.	*1ST ST.	W 12 FT.			WEST	0
COMMUNITY	*PHOENIX				EAST	2

Source Number 9

Source Number 10

ARIZONA DEPARTMENT OF TRANSPORTATION
TRAFFIC ENGINEERING SECTION
TRAFFIC STUDIES BRANCH

SIGNALIZED INTERSECTION
TABULATION
LEFT TURN PHASING

INTERSECTIONS WITH LEFT TURN PHASING

	LOCATION	WIDTH OF APPR.	SPD. LMT.	TYPE L/T PHAS.	LEADING/ LAGGING	DATE OF L/T TRN ON	PRIOR L/T ACCIDENTS	AFTER L/T ACCIDENTS
ROUTE/M.P.	US 60/ MP 143.40	N 10 FT.	50	PROT.	LEAD	10/20/81	10/20/79-	10/21/81-
CROSS ST.	DYSART RD.	S 10 FT.					-10/20/81	-6/30/85
COMMUNITY	SUPRIZE						0	0
ROUTE/M.P.	US 60/ MP 146.60	E 30 FT.	45	PROT.	LEAD	10/15/71	N/A PRIOR	7/1/82-
CROSS ST.	111TH AVE.	W 32 FT.					TO 1973	-6/30/85
COMMUNITY	MRCPA CNTY							W-1 E-0
ROUTE/M.P.	US 60/ MP 147.12	E 30 FT.	45	PROT.	LEAD	10/17/67	N/A PRIOR	7/1/82-
CROSS ST.	107TH AVE.	W 30 FT.					TO 1973	-6/30/85
COMMUNITY	MRCPA CNTY							0
ROUTE/M.P.	US 60/ MP 147.66	E 44 FT.	45	PROT.	LEAD	4/9/70	N/A PRIOR	7/1/82-
CROSS ST.	103RD AVE.	W 36 FT.					TO 1973	-6/30/85
COMMUNITY	MRCPA CNTY							W-2 B-1
ROUTE/M.P.	US 60/ MP 148.20	E 42 FT.	45	PROT.	LEAD	4/5/71	N/A PRIOR	7/1/82-
CROSS ST.	99TH AVE.	W 38 FT.					TO 1973	-6/30/85
COMMUNITY	MRCPA CNTY							W-1 E-1
ROUTE/M.P.	US 60/ MP 150.56	E 32 FT.	35	PROT.	LEAD	8/18/80	2/11/80-	2/12/83-
CROSS ST.	83RD AVE.	W 30 FT.				L/T	-2/11/83	-6/30/85
COMMUNITY	PEORIA					2/11/83	W-1 E-0	W-2 E-3
ROUTE/M.P.	US 60/ MP 151.56	E 38 FT.	45	PROT.	LEAD	1/4/68	8/12/78-	8/13/81-
CROSS ST.	75TH AVE.	W 36 FT.				L/T	-8/12/81	-8/13/84
COMMUNITY	PEORIA					8/12/81	W-9 E-3	W-12 E-4
ROUTE/M.P.	US 60/ MP 153.35	E 30 FT.	45	PROT.	LEAD	5/23/69	N/A PRIOR	7/1/82-
CROSS ST.	67TH AVE.	W 30 FT.					TO 1969	-6/30/85
COMMUNITY	GLENDALE							W-7 E-0
ROUTE/M.P.	US 60/ MP 154.39	E 30 FT.	40	PROT.	LEAD	5/20/69	N/A PRIOR	7/1/82-
CROSS ST.	61ST AVE.	W 30 FT.					TO 1969	-6/30/85
COMMUNITY	GLENDALE							0
ROUTE/M.P.	US 60/ MP 154.75	E 32 FT.	40	PROT.	LEAD	1/8/63	N/A PRIOR	7/1/82-
CROSS ST.	59TH AVE.	W 30 FT.					TO 1963	-6/30/85
COMMUNITY	GLENDALE							0
ROUTE/M.P.	US 60/ MP 155.45	E 24 FT.	40	PROT.	LEAD	10/25/54	N/A PRIOR	7/1/82-
CROSS ST.	55TH AVE.	W 30 FT.				L/T	TO 1959	-6/30/85
COMMUNITY	GLENDALE					7/31/59		W-1 E-2
ROUTE/M.P.	US 60/ MP 156.18	E 34 FT.	45	PROT.	LEAD	3/21/63	N/A PRIOR	7/1/82-
CROSS ST.	BETHANY HOME RD.	W 32 FT.					TO 1963	-6/30/85
COMMUNITY	GLENDALE							W-14 E-6

SP961-965-1
TRAFFIC STUDIES BRANCH - ARIZONA DEPARTMENT OF TRANSPORTATION
85010100008512312400 1 1 1

PHOENIX --*C723*
TRAFFIC ACCIDENT LISTING: ALL ACCIDENTS FROM 01/01/85 THRU 12/31/85 RUN ON 06/27/86 PAGE 100

86

I	ON STREET	SF	DIR	DIST	INTERSECT STREET	SF	D W	DATE MMDDHHHHRPT #	IN 12	VIOL V1V2	VISN V1V2	FA 12	PC 12	COND V1V2	TYPE V1V2	SO 12	HF CD	DT 12	VACT V1V2	RS 12	H R	L C	W C	CONTROL QRSTUVH	Q I	R J	S L	F A	T N	R C	UN RE	S C	M C
+	ARIZONA BILT	CI			24TH	ST	*4	1204131542145	44	0401	0101		11	0101	0202	NY	16	NS	0401	11	N	L	1	P	I	I	1		4			1	4
J	BASELINE	RD			7TH	AV	*2	1202155541775	11	0401	0101		11	0101	0402	NN	16	FW	0401	11	N	L	3	P D	I	I	1					1	4
J	BASELINE	RD			7TH	ST	*5	0502163016151	11	0401	0101		11	0101	0203	NY	16	FW	0401	11	N	L	1	P P	I	I	1			1		1	4
									1	01	01		1	01	05	N	16	W	06	1													
J	BASELINE	RD			7TH	ST	*4	0612175320934	21	0401	0303		11	0101	0304	NY	16	FW	0401	11	N	L	1	P	I	I	1		1			1	4
J	BASELINE	RD			7TH	ST	*5	0919191532119	16	0401	0101		11	0101	0102	YN	16	FW	0401	11	Y	D		P P	I	I	1					1	4
									1	01	01		1	01	02	N	16	N	01	1													
J	BASELINE	RD			7TH	ST	*2	0930124533391	13	0401	0101		11	0101	0402	NY	16	EW	0401	11	N	L	1	P P	I	I	1		1	3		1	4
J	BASELINE	RD			7TH	ST	*6	1004155533917	21	0418	0101		11	0101	0201	NN	16	FW	0401	11	N	L	3	P	I	I	1		1			1	4
J	BASELINE	RD			16TH	ST	*7	0525044918829	33	0402	0101		22	0101	0202	NY	16	FW	0401	11	N	3	1	P PP		I	1		3	3		1	4
T	BASELINE	RD			24TH	ST	*6	0510210217115	11	0401	0101		11	0101	0105	NY	16	EW	0401	11	N	D	3	P P	I	I	1					1	4
T	BASELINE	RD			24TH	ST	*1	1027005236970	66	0802	0116		2	01	0202	NN	16	WF	0401	11	Y	D	1	P P	I	I	1				02		4
									6	01	01		1	01	03	N	16	W	03	2													
+	BASELINE	RD			40TH	ST	*4	0925055032703	64	0401	1601		1	01	0215	NN	16	EW	0401	11	Y	3	1	P P	I	I	1		1			1	4
+	BASELINE	RD			40TH	ST	*2	1104080138041	11	0401	0101		11	0101	0202	NY	16	FW	0401	11	N	L	1	P	I	I	1					1	4
+	BASELINE	RD			48TH	ST	*5	0307170708539	11	0401	0101		11	0101	0101	NY	16	FW	0401	11	N	L	3	P P	I	I	1			1		1	4
+	BASELINE	RD			48TH	ST	*4	0717105024769	22	0401	0202		11	0101	0322	NY	16	FW	0401	11	N	L	1	P P	I	I	1		2	1		1	4
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+	BASFLINE	RD			48TH	ST	*4	1016064835433	11	0401	0101		11	0101	0401	NN	16	FW	0401	11	N	L	2	P	I	I	1					2	4
+	BASFLINF	RD			48TH	ST	*7	1026181036915	13	0401	1601		1	01	0404	NN	16	FW	0401	11	Y	D	1	P P	I	I	1		1				4
+	BASFLINE	RD			48TH	ST	*6	1109075538516	21	0401	0101		11	0101	0203	NN	16	FW	0401	11	N	L	1	P P	I	I	1		1	3		1	4
	BASELINE	RD	M	50	48TH	ST	*6	1109161938606	43	0401	0101		11	0101	0304	NN	16	WF	0401	11	N	L	1	P	D	N	1		2	1		1	4
+	BASELINE	RD			48TH	ST	*3	1210060042797	12	0401	0101		1	0101	0402	NY	16	EW	0401	11	N	D	1	P PP	I	I	1		1	3	05	1	4
+	BASELINE	RD			CENTRAL	AV	*3	0723115025405	13	0401	0101		11	0101	0115	NN	16	WE	0401	11	N	L	1	P P	I	I	1			1		1	4
									1	01	01		1	01	02	N	16	N	03	5									1				
+	BASELINE	RD			CENTRAL	AV	*5	1107191538497	11	0708	0101		11	0101	0304	NN	16	FW	0104	11	N	D	1	P PP	I	I	1			1	02	3	4
+	BASELINE	RD			CENTRAL	AV	*5	1205211642285	14	0401	0101		21	0101	1515	NN	16	SN	0401	11	N	D	3	P PP	I	I	1		1	3		1	4
+	BEARDSLEY	RD			15TH	AV	*2	1202175041793	11	0401	0202		11	0101	0403	NY	16	WE	0401	11	N	D	2	P P	I	I	1					2	4
+	BEARDSLFY	RD			19TH	AV	*3	0219010506310	32	0401	0101		21	0101	0402	NY	16	NS	0401	11	N	D	3	P PP	I	I	1		2	3		1	4
+	BEARDSLEY	RD			19TH	AV	*4	1225171645120	12	0401	0101		11	0101	0202	NY	16	WE	0401	11	N	L	1	P	I	I	1		1			1	4
	BEARDSLEY	RD	P	16	43RD	AV	*3	0312114009253	44	0401	0101		11	0101	0204	NN	16	WE	0401	11	N	L	1	P	I	N	1		3	1		1	4
+	BEARDSLEY	RD			43RD	AV	*3	1008081034403	13	0401	0301		11	0101	0202	NY	16	EW	0401	11	N	L	1	P	I	I	1		2			1	4
T	BECK	LA			25TH	AV	*5	1024183036635	22	0416	0101		12	0101	0417	NY	16	SN	0401	11	N	D	1		I	I	1		2			1	4
	BEHREND	DR	M	71	15TH	DR	*7	0223162006980	14	0401	1116		11	0101	0102	NY	16	WE	0401	11	N	L	1		D	N	1		1	2		1	4
	BELL	RD	P	200	7TH	AV	*6	0830182329737	44	0416	1616		11	0101	0404	NY	16	EW	0401	11	N	L	3	P	D	N	1		2	3	02	1	4
+	BELL	RD			7TH	ST	*1	0120195502413	14	0401	0101		11	0101	0415	NN	16	FW	0401	11	N	D	1	P PD	I	I	1		1	1		1	4
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	BELL	RD	P	94	7TH	ST	*6	0125183003035	11	0401	0202		11	0101	0101	NN	16	EW	0401	11	N	D	3	PP	D	N	1			1		3	4
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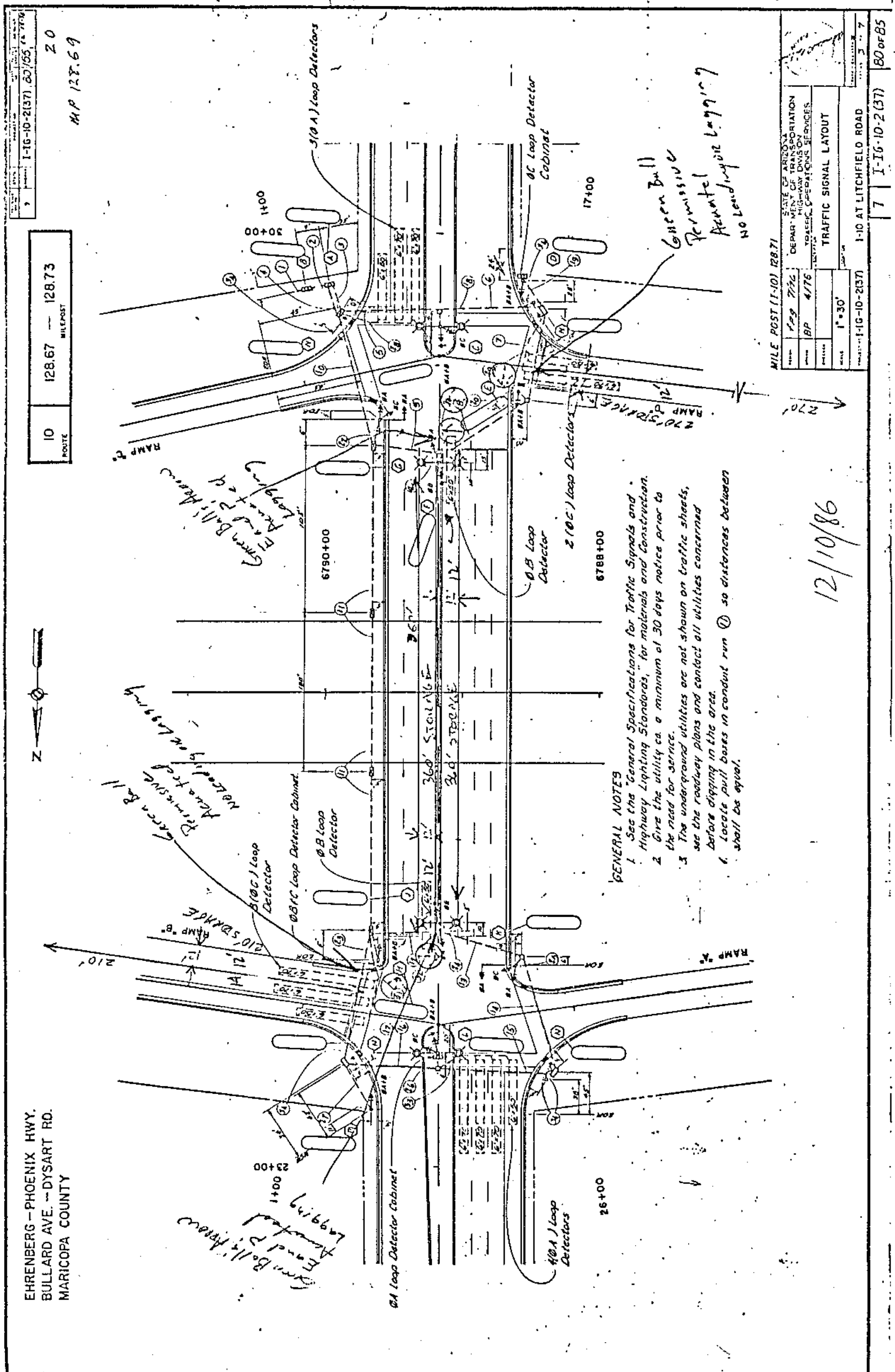
+	BELL	RD			7TH	ST	*1	0203002004116	41	0401	0101		21	0501	0204	NN	16	FW	0401	11	N	D	3	P PP	I	I	1		2	1		2	4
+	BELL	RD			7TH	ST	*3	0205132004520	13	0401	0101		11	0101	0202	NN	16	SN	0401	11	N	L	1	P	I	I	1		1			1	4
+	BELL	RD			7TH	ST	*2	0311080009004	11	0701	0101		11	0101	0103	NN	16	WE	0104	11	N	L	2	P	I	I	1					2	4
									1	01	02		1	01	04	N	16	S	03	5													
+	BELL	RD			7TH	ST	*3	0312124009322	31	0401	0303		11	0101	0303	NN	16	SN	0401	11	N	L	1	P P	I	I	1		1	1		1	4
+	BELL	RD			7TH	ST	*5	0321201510650	41	1601	1616		11	0101	0302	NN	16	SN	0401	11	N	D	1	P PP	I	I	1		1	3		1	4
	BELL	RD	P	0	7TH	ST	*2	0325160011188	11	0401	0202		11	0101	0104	NN	16	EW	0401	11	N	L	1	P	D	N	1			1		1	4

Source Number 11


EHRENBERG-PHOENIX HWY.
BULLARD AVE.-DYSART RD.
MARICOPA COUNTY
10 ROUTE
128.67 — 128.73 MILEPOST
GENERAL NOTES
1. See the "General Specifications for Traffic Signals and Highway Lighting Standards," for materials and Construction.
2. Give the utility co. a minimum of 30 days notice prior to the need for service.
3. The underground utilities are not shown on traffic sheets, see the roadway plans and contact all utilities concerned before digging in the area.
4. Locate pull boxes in conduit run (11) so distances between shall be equal.
STATE OF ARIZONA
DEPARTMENT OF TRANSPORTATION
HIGHWAY DIVISION
TRAFFIC OPERATIONS SERVICES
TRAFFIC SIGNAL LAYOUT
I-10 AT LITCHFIELD ROAD
I-IG-10-2(37)
80 of 85
MILE POST (I-10) 128.71
RAMP "A"
RAMP "B"
RAMP "C"
RAMP "D"
6790+00
6788+00
0A Loop Detector Cabinet
0B Loop Detector
0C Loop Detector Cabinet
12/10/86

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ARIZONA STATE DEPT OF TRANSPORTATION                               VERSION    12/03/86        PAGE
GP553.P.QSORS                                                      11.0 D     14.26.10           1

                                                                   PANVALET
                                           THE PROGRAM MANAGEMENT AND SECURITY SYSTEM

                      PROGRAMS AND ALL SUPPORTING MATERIALS COPYRIGHT 1982 BY PANSOPHIC SYSTEMS, INCORPORATED

++WRITE PRINT,SPEEDREZST
*           DATA SET SPEEDREZST AT LEVEL 046 AS OF 06/19/86
****************************************************************************          00001
**1*                                SPEEDREZST                                 **     00002
**2*************************************************************************          00003
**3*                           *  CARD 3 - CODE TABLES  *                      **     00004
**4*                           ----------------------                          **     00005
**5*                              LENGTH POINT CODES                           **     00006
**6*                                                                           **     00007
**7*             960      SPEED LIMIT IS SAME IN BOTH DIRECTIONS OF TRAVEL     **     00008
**8*             961      SPEED LIMIT IN POSITIVE DIRECTION OF TRAVEL          **     00009
**9*             962      SPEED LIMIT IN NEGATIVE DIRECTION OF TRAVEL          **     00010
*10*             BASED ON STANDARD ROADWAY WITH TRAVEL IN BOTH DIRECTIONS      **     00011
*11*             ---------------------------------------------------------     **     00012
*12*             961      SPEED LIMIT IS FOR ONEWAY DIRECTION OF TRAVEL        **     00013
*13*             BASED ON  INTERSTATE  OR  ROADWAYS WITH ONEWAY TRAVEL         **     00014
*14*                                                                           **     00015
*15*************************************************************************          00016
1A       SB0008                           SM      000                          10     00017
2M-0002M       000                                  M00270                     10     00018
3960022283         02228335                                SR4-3               10     00019
1A       SB0008                           SM      000                          20     00020
2M00270M       003                                  M00867                     20     00021
3960022283         02228335                                SR4-3               20     00022
1A       SB0008                           SM      003                          30     00023
2M00867M       004                                  M00374                     30     00024
3961022283         02228335                                SR4-3               30     00025
1A       SB0008                           SM      004                          40     00026
2M00374M       004                                  M00510                     40     00027
3960022283         02228335                                SR4-3               40     00028
1A       SB0008                           SM      004                          50     00029
2M00510M       005                                  M00730                     50     00030
3960022283         02228345                                SR4-3               50     00031
1A       SB0008                           SM      005                          60     00032
2M00730M       006                                  M00550                     60     00033
3960022283         02228355                                SR4-3               60     00034
1A       SB0008                           SM      006                          70     00035
2M00550M       011                                  M00960                     70     00036
3960022283         02228355                                SR4-3               70     00037
1A       SB0008                           SM      011                          80     00038
2M00960M       012                                  M00360                     80     00039
3960022283         02228355                                SR4-3               80     00040
1A       SB0008                           SM      012                          90     00041
2M00360M       012                                  M00539                     90     00042
3960022283         02228355                                SR4-3               90     00043
1A       SB0008                           SM      118                         100     00044
2M-0107M       118                                  M00330                    100     00045
3960100483         10048345                                SR32-3             100     00046
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Source Number 13

ARIZONA DEPARTMENT OF TRANSPORTATION
TRAFFIC ENGINEERING SECTION

Source Number 14

TURNING MOVEMENT VOLUME SURVEY

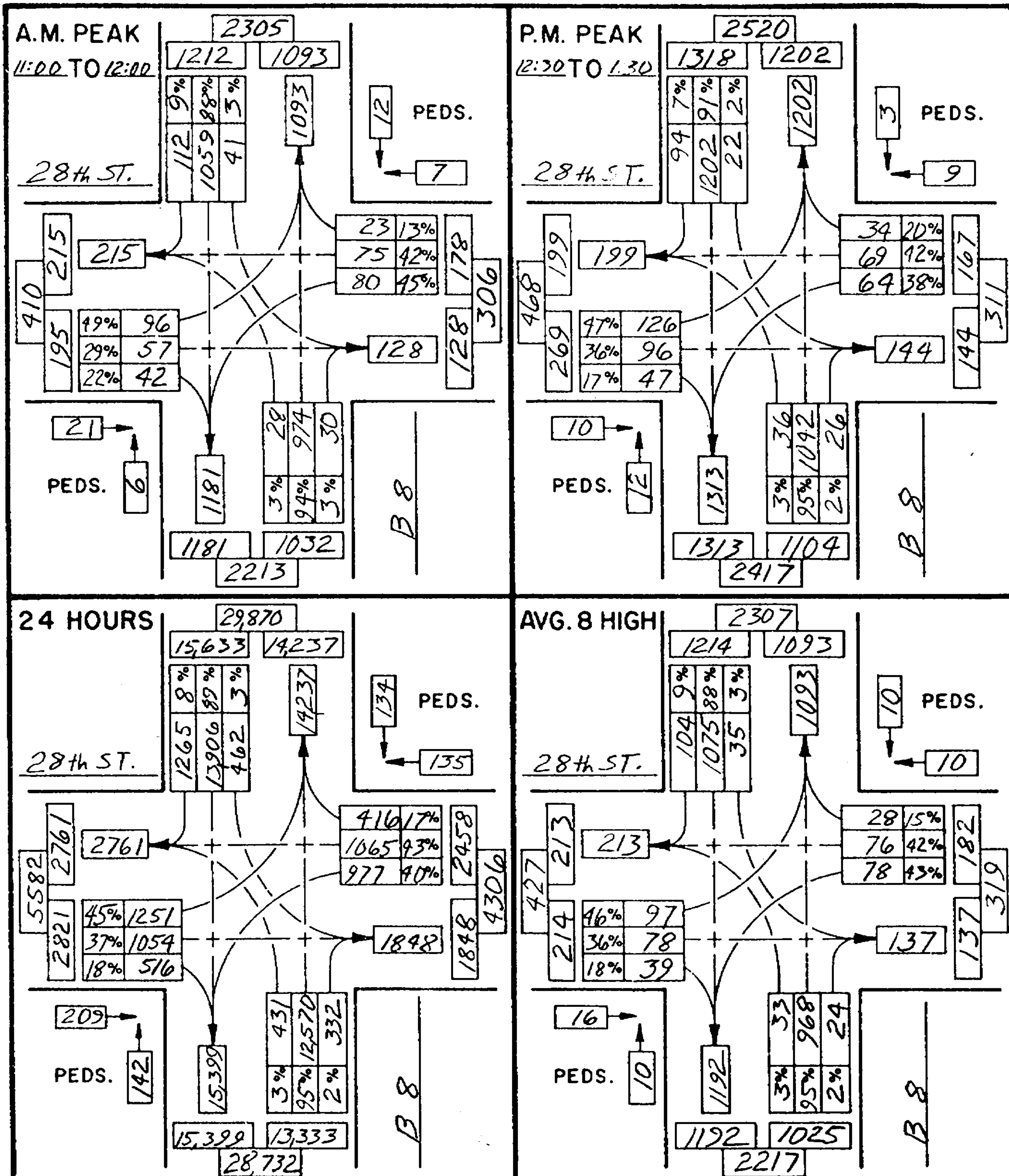
4620

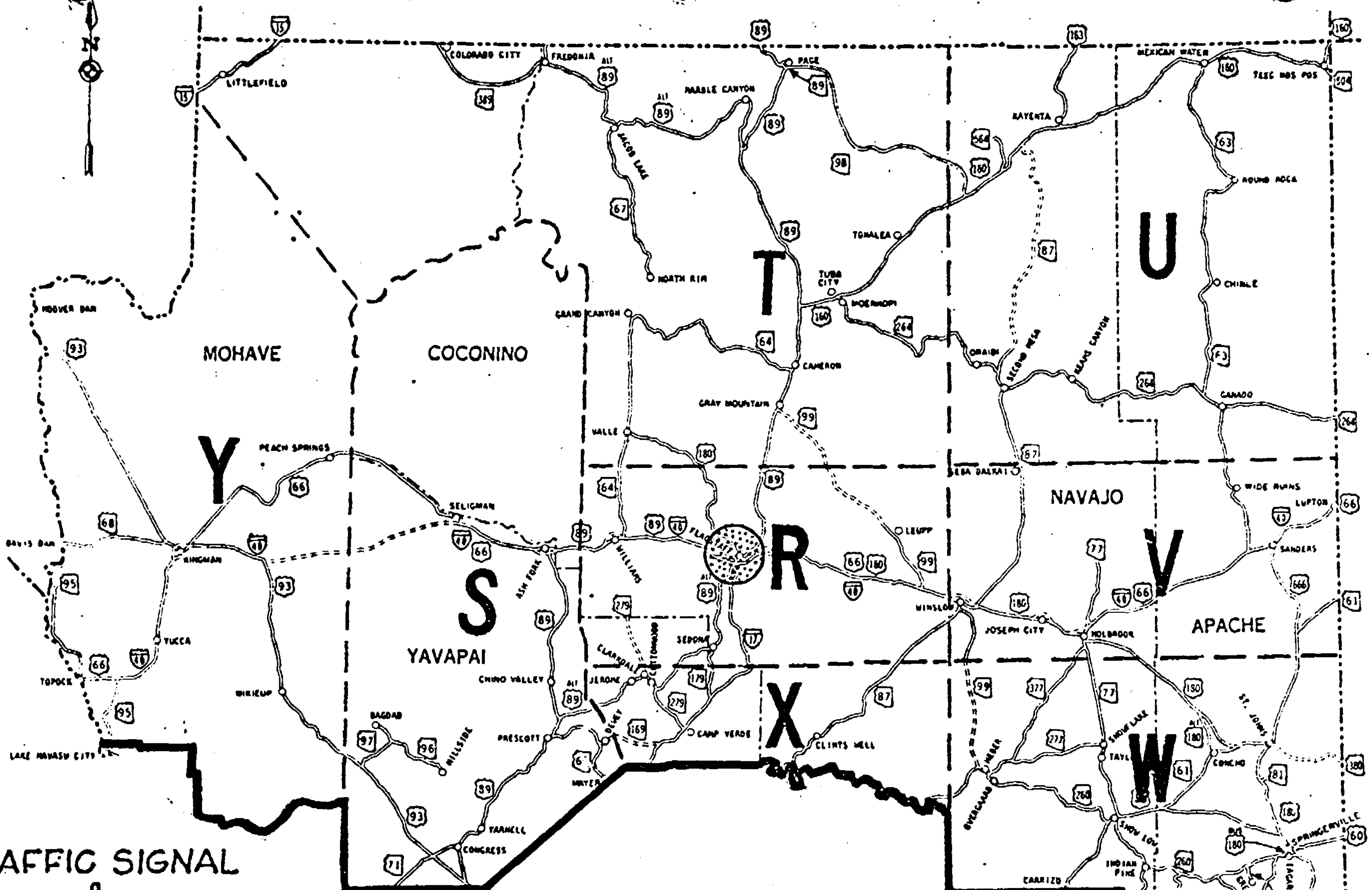
SUMMARY FORM

LOCATION: B 8 @ 28th ST. (YUMA)

MILEPOST: 3.63 DATE COUNTED: 12/16/85 TDS #X-H3-203-4

NORTH





TRAFFIC SIGNAL & LIGHTING MAINTENANCE SUB-DISTRICTS UNDER FLAGSTAFF SHOP

R - SUB-DISTRICT DESIGNATION (TYPICAL)

SUB-DISTRICT BOUNDARY

MAINTENANCE DISTRICT BDRY

MAINTENANCE CENTER

NO SCALE

APPENDIX C

SOLICITATION OF DATA FROM LOCAL JURISDICTIONS

Sample solicitation letter.

Attachment 1	was used to acquire information on signalized intersections where there had been not change in the type of left turn phasing
Attachment 2	was used to acquire information on signalized intersections where the type of left turn phasing was changed prior to April, 1988.
Attachment 3	was used to acquire information on signalized intersections where the type of left turn phasing was changed after March, 1988 or was planned to be changed by March 1991.

Arizona State University

College of Engineering and Applied Sciences
Center for Advanced Research in Transportation
Tempe, Arizona 85287-6306
602/965-2001
TLX 165878 COLL ENG TMPE

April 21, 1989

Frank Papscun, P.E.
Asst. Traffic Engineer
Maricopa County
Traffic Engineering Division
3325 West Durango Street
Phoenix, AZ 85009

Dear Frank:

The topic of left turn signal phasing has been one of on-going interest over several years in Arizona. Different jurisdictions have had different philosophies on which type of left turn signal phasing should be used. These differing philosophies have generated an interest in determining the actual operational and safety impacts of different types of left turn signal phasing.

The Arizona Department of Transportation has contracted with Arizona State University to objectively compare different types of left turn signal phasing, both in terms of operations (delay, etc.) and safety.

I seek your assistance in obtaining data to evaluate the relative safety of different types of left turn signal phasing. If you are able to assist ASU by providing information about selected intersections in your jurisdiction, I would be pleased to provide you with a copy of the study's results.

Through prior work in this study, data has been collected on phasing, geometry, traffic volumes and accidents for 495 signalized intersections on the state highway system. This database has given the project a start in determining the relative safety of different types of left turn signal phasing. Unfortunately, there are many gaps in the data and many types of information are lacking at a large number of intersections. As a result, the sample size for generating statistically sound accident rates is insufficient. This is particularly true for certain types of conditions such as an approach with exclusive/permissive left turn phasing and three opposing lanes of traffic. I seek your help in bolstering the database by providing information on signalized intersections in your jurisdiction.

For the safety analysis the project is interested in intersections that have any of the following types of left turn phasing:

permissive
leading exclusive/permissive
lagging exclusive/permissive
leading exclusive
lagging exclusive

The project is interested in intersections that have either two or three lanes of opposing traffic. (Lanes of opposing traffic are lanes on the opposite approach that handle through vehicles and/or right turning vehicles. A separate left turn lane on the opposite approach is not considered to be an opposing lane.) Because signalized intersections with one opposing lane for both through and right turning traffic are rare in Arizona, the project is not interested in this particular case. In addition, because exclusive left turn lanes are most commonly used in Arizona, the project is not interested in intersections that do not have exclusive left turn lanes.

The project is interested in obtaining information on as many intersections as possible. The project currently has information on a fairly large number of intersections with permissive phasing and two opposing lanes of traffic and intersections with leading exclusive and two opposing lanes of traffic. Thus, priorities are to obtain data for the other conditions.

There are three ways in which you can help:

1. General Case

   Provide phasing, geometric and traffic volume information for signalized intersections in your jurisdiction that are not on a state highway system. Attachment 1 is a convenient form that can be used for providing this information. It is important to concentrate on intersections where all of the needed data or nearly all of the needed data are available. Intersections for which only part of the data can be provided have limited usefulness and are of much lesser priority. ASU will obtain accident data from the accident Location Identification and Surveillance System (ALISS); you do not need to provide accident information. Remember that the project needs intersections with:

A) Two or three lanes of opposing traffic;

B) Exclusive left turn lanes;

C) Turning movement counts.

2. Conversions

The project is very much interested in intersections where the type of left turn phasing has been changed from one to another since 1980. Attachment 2 is a convenient form that can be used for providing the needed data. Again, it is important to concentrate on intersections where complete or near complete data are available. ASU will obtain accident information from AlLISS for those intersections that you submit.

3. Recent or Proposed Conversions

Provide information on intersections where the type of left turn phasing has been changed within the last 12 months or where the type of left turn phasing is planned or programmed to be changed within the next 24 months. Attachment 3 is a convenient form on which this information can be submitted.

I look forward to your help and cooperation. If you have any questions, please do not hesitate to call me. So that timely progress can be made on this research effort, I would appreciate hearing from you by May 25. Thank you.

Very truly yours,

Jonathan Upchurch, P.E.
Acting Director

enclosures

ATTACHMENT 1

1. RECORD NUMBER (leave blank) ________ ______

2. NORTH-SOUTH STREET NAME ______________________

3. EAST-WEST STREET NAME ______________________

4. JURISDICTION ______________________

5. TYPE OF LEFT TURN PHASING*

NORTH LEG (FOR SOUTHBOUND TRAFFIC)	P	E/P	E	Prohib.	Lead	Lag
SOUTH LEG (FOR NORTHBOUND TRAFFIC)	P	E/P	E	Prohib.	Lead	Lag
EAST LEG (FOR WESTBOUND TRAFFIC)	P	E/P	E	Prohib.	Lead	Lag
WEST LEG (FOR EASTBOUND TRAFFIC)	P	E/P	E	Prohib.	Lead	Lag

* Circle the appropriate description for each leg

P = Permissive

E/P = Exclusive/Permissive

E = Exclusive

PROHIB. = Prohibited

For Exclusive/Permissive, indicate if the left turn phase is leading (Lead) or lagging (Lag).

6. DATE ON WHICH THE TYPE OF LEFT TURN PHASING WAS INSTALLED/CHANGED (If prior to 1983, enter "Pre-1983")

NORTH LEG (FOR SOUTHBOUND TRAFFIC) ________

SOUTH LEG (FOR NORTHBOUND TRAFFIC) ________

EAST LEG (FOR WESTBOUND TRAFFIC) ________

WEST LEG (FOR EASTBOUND TRAFFIC) ________

7. IS THERE AN EXCLUSIVE LEFT TURN LANE?

NORTH LEG (FOR SOUTHBOUND TRAFFIC)	YES	NO
SOUTH LEG (FOR NORTHBOUND TRAFFIC)	YES	NO
EAST LEG (FOR WESTBOUND TRAFFIC)	YES	NO
WEST LEG (FOR EASTBOUND TRAFFIC)	YES	NO

8. TOTAL NUMBER OF THRU PLUS RIGHT TURN LANES (Do not include exclusive left turn lane.)

NORTH LEG (FOR SOUTHBOUND TRAFFIC) ______

SOUTH LEG (FOR NORTHBOUND TRAFFIC) ______

EAST LEG (FOR WESTBOUND TRAFFIC) ______

WEST LEG (FOR EASTBOUND TRAFFIC) ______

YOU MAY WANT TO DRAW A SIMPLE SKETCH OF THE INTERSECTION SHOWING EACH LANE AND THE MOVEMENTS PERMITTED FROM EACH

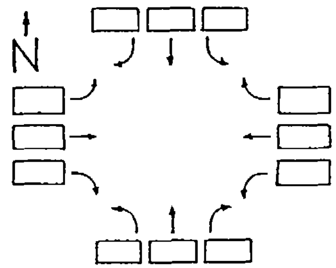
9. HAS THERE BEEN ANY CHANGE IN INTERSECTION GEOMETRY (ITEMS 7 AND 8 ABOVE) SINCE 1982?

YES NO

IF YES, WHAT WERE THE CHANGES AND WHEN WERE THEY MADE?

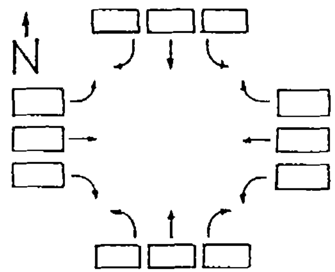
10. PROVIDE TURNING MOVEMENT COUNTS SHOWING THE 24 HOUR VOLUME FOR EACH TURNING MOVEMENT.

(It is understood that turning movement counts are very rarely made for a 24 hour period. Please estimate the 24 hour volume based upon actual counts made over a shorter time period.)



DATE OF COUNT ________

If more than one turning movement count has been made since 1982, please provide data for the additional counts.



DATE OF COUNT ________

ATTACHMENT 2

USE THIS FORM ONLY FOR THOSE LOCATIONS WHERE THE TYPE OF LEFT TURN PHASING WAS CONVERTED PRIOR TO APRIL, 1988.

1. RECORD NUMBER (leave blank) ________ ______

2. NORTH-SOUTH STREET NAME ________________

3. EAST-WEST STREET NAME ________________

4. JURISDICTION ________________

5. DATE ON WHICH THE TYPE OF LEFT TURN PHASING WAS CHANGED

   NORTH LEG (FOR SOUTHBOUND TRAFFIC) ________________

   SOUTH LEG (FOR NORTHBOUND TRAFFIC) ________________

   EAST LEG (FOR WESTBOUND TRAFFIC) ________________

   WEST LEG (FOR EASTBOUND TRAFFIC) ________________

6. TYPE OF LEFT TURN PHASING BEFORE CONVERSION*

NORTH LEG (FOR SOUTHBOUND TRAFFIC)	P	E/P	E	Prohib.	Lead	Lag
SOUTH LEG (FOR NORTHBOUND TRAFFIC)	P	E/P	E	Prohib.	Lead	Lag
EAST LEG (FOR WESTBOUND TRAFFIC)	P	E/P	E	Prohib.	Lead	Lag
WEST LEG (FOR EASTBOUND TRAFFIC)	P	E/P	E	Prohib.	Lead	Lag

* Circle the appropriate description for each leg

P = Permissive

E/P = Exclusive/Permissive

E = Exclusive

PROHIB. = Prohibited

For Exclusive/Permissive, indicate if the left turn phase is leading (Lead) or lagging (Lag).

7. TYPE OF LEFT TURN PHASING AFTER CONVERSION.*

NORTH LEG (FOR SOUTHBOUND TRAFFIC)	P	E/P	E	Prohib.	Lead	Lag
SOUTH LEG (FOR NORTHBOUND TRAFFIC)	P	E/P	E	Prohib.	Lead	Lag
EAST LEG (FOR WESTBOUND TRAFFIC)	P	E/P	E	Prohib.	Lead	Lag
WEST LEG (FOR EASTBOUND TRAFFIC)	P	E/P	E	Prohib.	Lead	Lag

8. IS THERE AN EXCLUSIVE LEFT TURN LANE?

NORTH LEG (FOR SOUTHBOUND TRAFFIC)	YES	NO
SOUTH LEG (FOR NORTHBOUND TRAFFIC)	YES	NO
EAST LEG (FOR WESTBOUND TRAFFIC)	YES	NO
WEST LEG (FOR EASTBOUND TRAFFIC)	YES	NO

9. TOTAL NUMBER OF THRU PLUS RIGHT TURN LANES (Do not include exclusive left turn lane.)

   NORTH LEG (FOR SOUTHBOUND TRAFFIC) ____

   SOUTH LEG (FOR NORTHBOUND TRAFFIC) ____

   EAST LEG (FOR WESTBOUND TRAFFIC) ____

   WEST LEG (FOR EASTBOUND TRAFFIC) ____

YOU MAY WANT TO DRAW A SIMPLE SKETCH OF THE INTERSECTION SHOWING EACH LANE AND THE MOVEMENTS PERMITTED FROM EACH

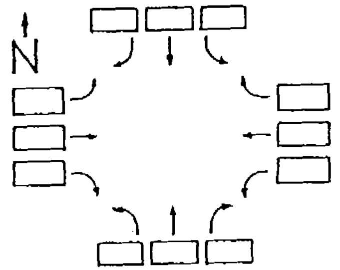
10. HAS THERE BEEN ANY CHANGE IN INTERSECTION GEOMETRY (ITEMS 8 AND 9 ABOVE) SINCE 1982?

    YES NO

    IF YES, WHAT WERE THE CHANGES AND WHEN WERE THEY MADE?

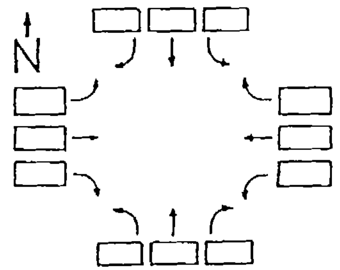
11. PROVIDE TURNING MOVEMENT COUNTS SHOWING THE 24 HOUR VOLUME FOR EACH TURNING MOVEMENT.

    (It is understood that turning movement counts are very rarely made for a 24 hour period. Please estimate the 24 hour volume based upon actual counts made over a shorter time period.)



DATE OF COUNT ________

If more than one turning movement count has been made since 1982, please provide data for the additional counts. It would be particularly helpful to have turning movement counts made both before and after the conversion in the type of left turn phasing.



DATE OF COUNT ________

ATTACHMENT 3

<u>INTERSECTIONS WHERE THE TYPE OF LEFT TURN PHASING HAS BEEN CHANGED SINCE MARCH, 1988 OR IS PLANNED TO BE CHANGED BY MARCH, 1991</u>

JURISDICTION ______________________

NORTH-SOUTH STREET NAME ______________________

EAST-WEST STREET NAME ______________________

CURRENT OR BEFORE TYPE OF LEFT TURN PHASING*

NORTH LEG (FOR SOUTHBOUND TRAFFIC)	P	E/P	E	Lead	Lag
SOUTH LEG (FOR NORTHBOUND TRAFFIC)	P	E/P	E	Lead	Lag
EAST LEG (FOR WESTBOUND TRAFFIC)	P	E/P	E	Lead	Lag
WEST LEG (FOR EASTBOUND TRAFFIC)	P	E/P	E	Lead	Lag

FUTURE OR AFTER TYPE OF LEFT-TURN PHASING*

NORTH LEG (FOR SOUTHBOUND TRAFFIC)	P	E/P	E	Lead	Lag
SOUTH LEG (FOR NORTHBOUND TRAFFIC)	P	E/P	E	Lead	Lag
EAST LEG (FOR WESTBOUND TRAFFIC)	P	E/P	E	Lead	Lag
WEST LEG (FOR EASTBOUND TRAFFIC)	P	E/P	E	Lead	Lag

IF ALREADY CHANGED, THE DATE OF CONVERSION ______________

IF PLANNED, THE PROJECTED DATE OF CONVERSION ______________

* Circle the appropriate description

P Permissive

E/P Exclusive/Permissive

E Exclusive

For Exclusive/Permissive, indicate if the left turn phase is leading (Lead) or lagging (Lag).

APPENDIX D

VALIDATION TESTING OF THE TEXAS MODEL

BACKGROUND INFORMATION

Traffic simulation models are computer programs that are designed to represent realistically the behavior of the physical system. The major advantage of using a simulation model is its ability to compare and evaluate among alternate solutions of a single problem by changing the variables in the model without physically going out to the field to make the change. This analysis tool is effective in comparing different scenarios before deciding on one to implement thus reducing costs that would otherwise be incurred if an unsuccessful scenario is implemented. Another advantage is that a simulation model can give results for variables that would otherwise be difficult to obtain from field measurements.

Painting a rosy picture about computer simulation could be deceiving. The user of computer simulation models has to be careful about how the model is being used and how much faith he or she has in the results. A well validated simulation model can be a powerful tool. Validation involves large scale field data collection for different settings followed by using the model to create the same circumstances in the computer. The produced results are then compared against the field data to decide whether the model realistically replicates the real world.

This task of the study focused on traffic operations at isolated signalized intersections. The intersection is one of the most important components of a traffic network in the urban area. One of the traffic simulation models developed for isolated intersections is the TEXAS (Traffic *EXperimental* and Analytical Simulation) simulation model.

The main goal of this task was to utilize measure of effectiveness data from previous field studies and compare it with the measures of effectiveness predicted by the TEXAS simulation model. The main purpose of this exercise was to attempt to validate the simulation model and check its ability to replicate the real world. The field data used for the validation purpose was composed of three related studies. A major part of the data for this effort was taken from the research project "Left Turn Signal Warrants for Arizona" (15).

The remainder of the data was taken from two previous Master of Science theses which were titled "Effects of Changing Permissive Left Turn Phasing to Exclusive/Permissive" (17) and "Effects of Changing Exclusive/Permissive Left Turn Phasing From Variable to Fixed Cycle Length" (20).

THE TEXAS SIMULATION MODEL

The TEXAS (Traffic EXperimental and Analytical Simulation) model is a microscopic simulation model. It was developed by the University of Texas at Austin for the Texas State Department of Highways and Public Transportation (6,7,8,9). In a microscopic model each vehicle in the traffic stream is monitored individually. The model can be used as a tool by transportation engineers to evaluate traffic performance at isolated intersections operating under various types of intersection control. It is mostly a deterministic model in the sense that none of the response decisions are made on a probability basis.

The model is divided into three main parts, a geometry processor called GEOPRO, a driver-vehicle processor called DVPRO, and a traffic simulation processor called SIMPRO. The geometry processor accepts data concerning the physical configuration of the intersection such as the number of legs and the number of lanes and their widths. The processor calculates the geometric path of vehicles on the approaches and within the intersection, identifies points of conflict between intersection paths, and determines the minimum available sight distance along each inbound approach.

The input requirements for this processor include approach information such as the number of inbound and outbound approaches, the speed limit for each approach, the number of lanes for each approach, and the maximum angular deviation of through movement and U-turn movement for each approach. Lane information, such as the width of each lane, the geometry of each lane, and the turning movements generated from each inbound lane and accepted by each outbound lane, is also required. The geometry of a lane just mentioned describes whether a lane is fully open or partly blocked which is important for the representation of conditions such as turning pocket lanes, bus stops, construction barricades, or loading zones.

The driver-vehicle processor stores information related to the driver characteristics and the vehicle characteristics in the traffic stream. The processor generates driver-vehicle units for use by the traffic simulation processor. Each one of these units is randomly assigned a driver class, a vehicle class, a lane, a turning movement and a desired speed using a discrete empirical distribution. The total number of driver-vehicle units generated depends on the vehicular volume and on the simulation time. The processor then orders these units sequentially by queue-in time.

The input data required for this processor, for each intersection approach, includes the headway distribution and its parameter, the minimum headway, the hourly traffic volume, the mean and 85th percentile speed, the turning distribution (percent of vehicles going to each outbound approach), the lane occupancy, the time for generating traffic, and the number of driver and vehicle classes . The model has seven different types of headway distributions to choose from. They are the constant, the Erlang, the gamma, the lognormal, the negative exponential, the shifted negative exponential, and the uniform distributions. The time for generating traffic is made up of the start-up time plus the simulation time. In the start-up time period the flow through the system has not attained a steady state condition and so performance statistics are unreliable. After the specified start-up time, flow is assumed to have reached steady state and it is followed by the simulation time period. In this period, fluctuations in the system are minimized and performance statistics are reliable. Another input requirement for this processor is the percent of left turning vehicles to enter in the median lane and the percent of right turning vehicles to enter in the curb lane.

The traffic simulation processor uses the output from the previous two processors and processes each driver-vehicle unit through the intersection system. This processor simulates the traffic behavior of each driver-vehicle unit depending on its surrounding conditions. The driver-vehicle unit is monitored moment by moment from the time it enters an inbound approach until it leaves the system from an outbound approach. The processor adjusts the movement of the driver-vehicle unit depending on various elements such as the indication of the traffic control device, the presence of a vehicle ahead and if the driver- vehicle unit is in a car-following situation.

The input data requirements for a simulation run are the type of intersection control, the start-up and simulation time, the time step increment for simulation, the maximum clear distance for being in a queue, the speed for "delay below XX miles per hour (mph)", the time for lead and lag safety zone for conflict checking, and the parameter values for the car following equation. The available intersection control options to choose from are traffic signals with pretimed, semi-actuated, or fully-actuated controllers, all-way stop sign, two- way stop sign, yield sign, and uncontrolled. A specified discrete time increment is used as the fixed time basis for scanning the intersection and updating each driver-vehicle unit. The model recommends the use of 0.5 seconds for the simulation of unsignalized intersections and 1.0 seconds for the simulation of signalized intersections.

Once SIMPRO has been successfully executed, the model can be prepared to display the simulation in graphics format. Two programs are utilized for this activity; DISPRE, which is a display preparation program; and DISPRO, which is the display processor where the animated graphics is shown.

After running DISPRE, the program DISPRO is executed. This displays the intersection layout on the screen and then simulates the position of the vehicles from the time they enter the system to the time they leave it. This information can be displayed in real-time or in a stop and go mode that is manually run. The graphic display is useful in detecting errors in the intersection geometry which may occur during the input of the offset of each leg centerline from the intersection center. It is also used to detect errors in the input of the phasing sequence for signalized intersections. The graphic display shows the signal indication for each approach, and by viewing the animation, the user is able to detect if the green interval sequence is correctly represented.

OBJECTIVE

The principal objective of this task was to validate the TEXAS simulation model using existing field data of isolated signalized intersections for comparison purposes. Validating the model is needed as a first step before it is used by traffic engineers and traffic departments as a design and decision making tool. Validation is needed to determine if the model behaves in a way similar to the real world when run under the same conditions as the field data.

The validation process was attempted by comparing the results of the measures of effectiveness obtained from the simulation runs with those obtained from field data. Statistical methods were used to test the significance between the simulation and field results.

DESCRIPTIONS OF THE INTERSECTIONS

Eight intersection conditions, each having available field data, were used in this study. Six intersections located in the Greater Phoenix area were used for the previous left turn warrants study (1). The intersections were:

- University and Alma School.
- Alma School and Broadway.
- Priest and Broadway.
- Thomas and 44th Street.
- Scottsdale and Thomas.
- Dobson and Main.

These were chosen because they represented a wide variety of intersection characteristics. The intersections cover a range of values for the geometry such as the number of opposing lanes, the type of left turn phasing, left turn volume, and the volume of opposing traffic. Table D-1 documents selected data items for the six intersections. The near side approach means the intersection approach at which the time lapse camera was placed.

Subsequent to the left turn warrants study (15), the intersection of Thomas and 44th Street

TABLE D-1: INTERSECTION DATA USED IN THE STUDY

Intersection Name	Major Street Near Side Approach			Major Street Far Side Approach			Control Type	Left Turn Control	No. of Phases	Major Street ADT (1984)
	No of Inbound Lanes	No. of Outbound Lanes	Left Turn Pocket Lane	No of Inbound Lanes	No. of Outbound Lanes	Left Turn Pocket Lane				
UNIVERSITY AND ALMA SCHOOL	3	2	YES	3	2	YES	PRETIMED	PERMISSIVE	2	26860
ALMA SCHOOL AND BROADWAY	3	2	YES	3	2	YES	ACTUATED	EXCLUSIVE/ PERMISSIVE	8	27210
BROADWAY AND PRIEST	4	2	YES	3	2	YES	ACTUATED	EXCLUSIVE	8	35400
44TH STREET AND THOMAS	4	3	YES	4	3	YES	PRETIMED	PERMISSIVE	2	43500
THOMAS AND SCOTTSDALE	3	3	YES	4	2	YES	ACTUATED	EXCLUSIVE/ PERMISSIVE	8	27860
MAIN AND DOBSON	4	3	YES	4	3	YES	ACTUATED	EXCLUSIVE	8	23100

was operated under two other different scenarios. The original scenario had a pretimed signal with permissive left turn phasing. The second scenario involved changing the left turn phasing from permissive to exclusive/permissive (see Stonex (17)). The signal was also changed to a fully-actuated signal but with a variable cycle length which disrupted the vehicular progression. The third scenario had a phasing similar to the previous scenario but with a fixed cycle length which helped vehicular progression (see Warne (20)).

Therefore a total of eight different intersection conditions were available for use in this research. Two of the conditions address permissive left turn phasing, two address leading exclusive left turn phasing, and the remaining four conditions address leading exclusive/permissive left turn phasing.

Out of the six different intersections being studied, three intersections have two opposing lanes which the left turning vehicles have to cross, while the other three intersections have three opposing lanes to be crossed. This variety was intentional in the selection of the intersections because previous studies have shown that drivers making a left turn have greater difficulty in identifying acceptable gaps when there are three lanes of opposing traffic than when there are only two opposing lanes(15). This wide range of intersection geometric features helped in testing the model's adequacy to replicate real world driver characteristics.

DATA COLLECTION

The TEXAS simulation model is a data hungry program and requires a considerable amount of input data. Extensive data collection is important for properly recreating the field environment on the computer. These requirements help in minimizing errors that could develop in the later stages due to lack of data.

The data that was collected from the previous three studies (15, 17, 20) was used as the basis for this study and was complimented with more data collection. The extra data was needed because the three studies collected data for only two of the four approaches at each intersection.

The data was collected in each of the previous studies by filming each one of the intersection scenarios using a time-lapse camera. Each scenario was filmed continuously for seven or eight hours during the day. This filming procedure captured morning and evening peaks as well as off peak periods. The camera was situated about 300 feet in advance of the intersection. The location and orientation of the camera provided a good view of the two intersection approaches parallel to the camera's direction and of the middle of the intersection, but it was occasionally difficult to identify the green arrow indication and the green ball indication of the signal head. The filming was conducted on weekdays.

The data collected from the previous studies was for the two approaches parallel to the camera's field of view. The data included the number of vehicles stopped, the number of vehicles stopping, and the number of vehicles not stopping for each of the two approaches. Within each approach, this data was collected for the left turn movement and for the through movement separately. For those studies, the definition of the through movement incorporated both the through and right turns (20) For each hour of filming the data was set up in convenient five minute intervals and was used to calculate stopped delay. Additional data collected for those studies included the signal timing plans and intersection geometry. Intersection configuration for the approaches perpendicular to the camera's field of view was obtained from city drawings that showed the number of lanes, the lane widths, and the number and position of the loop detectors.

Additional data, not extracted from the film in the previous studies, was extracted in this study. One kind of additional data was vehicle type. The TEXAS model has twelve different vehicle classes. For practical purposes these were reduced to seven different classes which were a sports car, a compact, a medium car, a large car, a single unit truck using gas, a single unit truck using diesel fuel, and a semi-trailer truck. Viewer judgement was required in categorizing the vehicles viewed to their appropriate class. Trucks were usually categorized as single unit vehicles using gas, while buses were categorized as single unit vehicles using diesel fuel.

A second kind of additional data was headway distribution data which was collected for the near side approach parallel to the camera's field of view. The time between two successive free flowing vehicles was recorded for each open lane of the approach separately. The data was recorded for the vehicles traveling freely through the intersection during a green period and without slowing down due to a queue. When this condition occurred, the time when a lead vehicle passed a fixed point on the screen was recorded and the time that subsequent vehicles passed the same point was also recorded until the free flow state was interrupted. The difference between these recorded times gave the headway in seconds.

A third kind of additional data was a continuous record of signal timing. This data was collected randomly in 5 minute intervals in each hour.

After acquisition of the additional data for the eight intersection conditions and the selection of the default values for the variables that had no data collected, the TEXAS model was used to simulate the intersection operation. For each set of conditions that were simulated, 15 replications were conducted, each using a different random seed. Mean values of the outputs from the 15 replications were used to compare with the field data acquired in the three previous studies.

Each one of the eight intersection conditions was analyzed separately. The volume data for each intersection was divided into 10 minute intervals. For each hour of film the first five 10 minute intervals were considered. The last 10 minute interval was omitted because each film was not exactly one hour long and varied from 52 minutes in some cases to 59 minutes in others.

Determination of The Critical Time Periods

Each intersection was divided into 35 to 40 intervals depending on the number of hours of film (7 or 8) for each location. The process of taking every interval (approximately 35 intervals) and running it 15 times for each intersection condition would have been extremely time consuming. Therefore it was decided to choose representative intervals for each intersection which would be the most critical.

The procedure undertaken was to arrange the thirty five to forty 10 minute approach volumes for the near side approach of an intersection in ascending order. The emphasis was on the two approaches parallel to the camera's field of view because they were the ones for which average stopped delay was calculated in the previous studies. Figure D-1 illustrates this procedure. The table contains a column for the left turn volume of the near approach, the percent of left turns, the volume of the opposing approach, the cycle length, and the product parameter.

The product parameter is reached by multiplying the approach volume by the percentage of left turns and by the opposing volume. The range of the approach volume is divided into 6 to 8 intervals and a frequency table is generated then a histogram is drawn. Figure D-2 shows the histogram for one of the intersection conditions and it results in a distribution which is similar in shape to a normal distribution. Out of each frequency interval the critical reading is selected based on the greater value of the product parameter. This was the basis for the selection procedure of the critical 10 minute time periods. The actual selection differed somewhat depending on the type of left turn phasing at that particular intersection. The selection figures and their corresponding histograms for the remaining seven intersection conditions are documented in Appendix D-1.

For permissive left turn phasing the most critical parameter is the volume on the opposing approach. Therefore for this condition the critical 10 minute time period chosen in each interval is the one satisfying the greater value of the product parameter. If one of the intervals has more than one cycle length, the selection process is conducted for each value of the cycle length separately.

The critical parameter for the exclusive/permissive left turn phasing is also the volume on the opposing approach for the permissive part and the left turn volume on the near approach for the exclusive part. The selection process for this case involves finding, within each interval, the 10 minute period which has the greater value of the product parameter and at the same time the greater value of the left turn volume on the near approach. The best selection is a 10 minute period which satisfies both criteria. If this is not possible then two 10 minute periods are selected - one for each criteria. Again, if there are more than one cycle length in the interval, the selection is conducted for each cycle length separately.

For the exclusive left turn phasing the critical parameter is the left turn volume on the near

INTERSECTION : ALMA SCHOOL AND BROADWAY (EXCLUSIVE/PERMISSIVE LEFT TURNS)

APPROACH : NORTHBOUND (LEG 3)

HOURLY VOLUME (VPH)	LEFT TURN VOLUME	PERCENT OF LEFT TURNS	OPPOSING VOLUME (VPH)	CYCLE LENGTH (SEC)	PRODUCT PARAMETER	
765	107	14	900	148.5	96390	
786	165	21	1128	148.5	186188	— 1
858	129	15	858	148.5	110425	
864	147	17	774	148.5	113685	
888	186	21	1050	148.5	195804	— 2
912	128	14	792	148.5	101123	
930	140	15	990	148.5	138105	
942	170	18	930	148.5	157691	
948	142	15	864	148.5	122861	
954	153	16	930	148.5	141955	
954	181	19	924	148.5	167484	
954	105	11	954	148.5	100113	
960	154	16	1128	148.5	173261	
978	137	14	888	148.5	121585	
996	100	10	804	148.5	80078	
1002	160	16	1434	148.5	229899	— 3
1014	172	17	930	148.5	160313	
1044	188	18	810	148.5	152215	— 4
1044	146	14	870	148.5	127159	
1068	171	16	1158	148.5	197879	
1068	182	17	1344	148.5	244017	
1080	173	16	978	148.5	168998	
1086	185	17	1134	148.5	209359	
1098	285	26	1236	148.5	352853	— 5
1104	188	17	1098	148.5	206073	
1116	246	22	1116	148.5	274000	
1134	91	8	1446	148.5	131181	
1140	160	14	1266	148.5	202054	
1146	218	19	954	148.5	207724	
1152	207	18	1446	148.5	299843	— 6
1158	151	13	1572	148.5	236649	
1158	139	12	1512	148.5	210108	
1164	128	11	1140	148.5	145966	
1170	140	12	1350	148.5	189540	
1194	96	8	1452	148.5	138695	
1194	215	18	1308	148.5	281115	— 7
1272	191	15	1140	148.5	217512	
1290	232	18	930	148.5	215946	— 8
1320	198	15	984	148.5	194832	
1332	173	13	918	148.5	158961	

FREQUENCY TABLE

750-850	2
850-950	7
950-1050	10
1050-1150	10
1150-1250	7
1250-1350	4

Figure D-1. SELECTION OF THE CRITICAL 10 MINUTE PERIODS

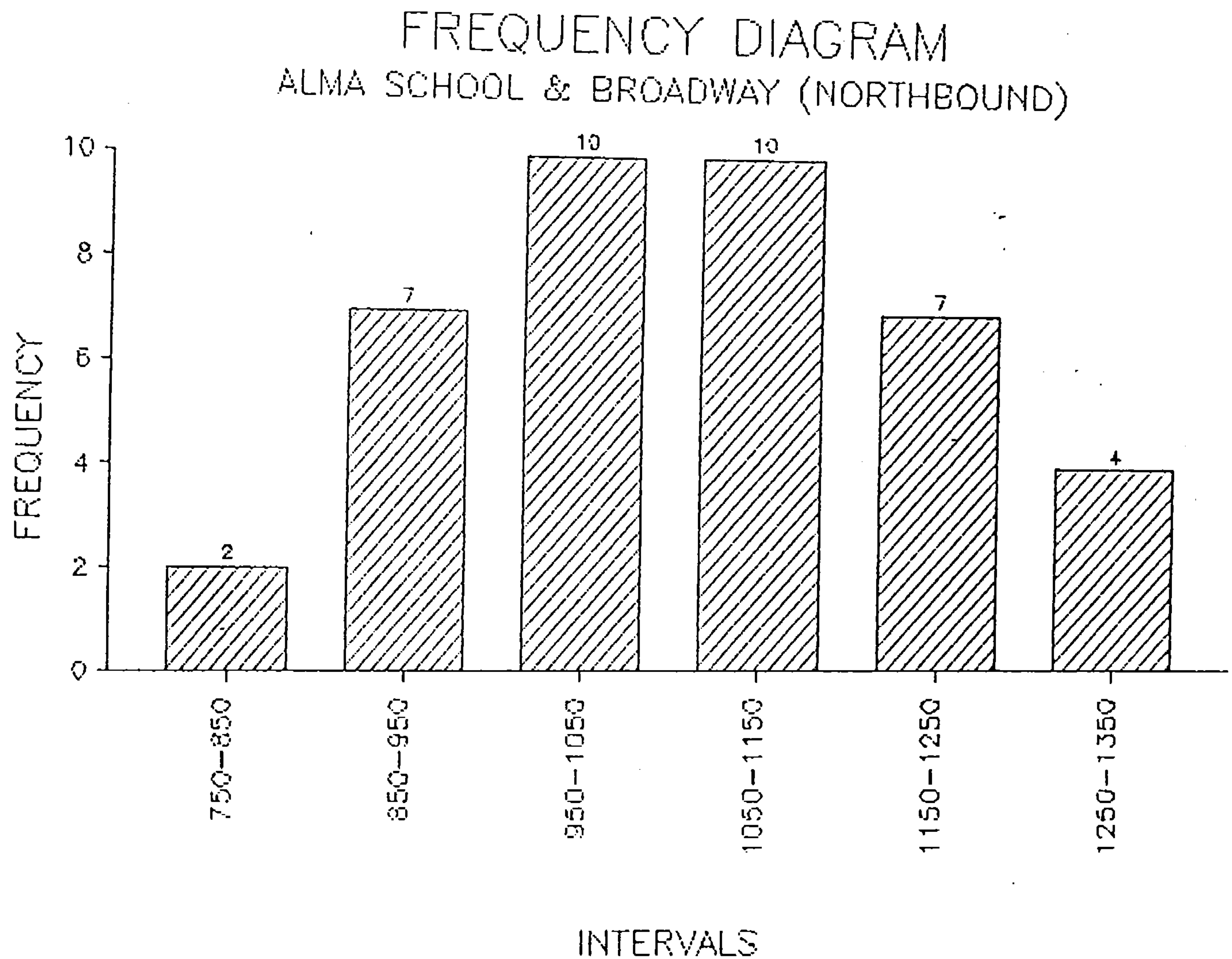


Figure D-2. HISTOGRAM OF THE FREQUENCY INTERVALS approach. The selection criteria for this condition is the greater value of the left turn volume on the near approach. Usually this 10 minute period would have a high value for the product parameter but not necessarily the greater value. When there is more than one cycle length in each interval, the selection is conducted for each cycle length separately.

Table D-2 summarizes the findings of the selection process for all eight intersection conditions. A total of 87 critical 10 minute periods were selected and each one of the periods was run 15 times using the TEXAS model resulting in 1305 individual runs.

Table D-2 - Summary of the Critical Time Periods Selected

Intersection Condition	Number of Intervals	Number of 10 min Periods Selected
University and Alma School	9	11
Alma School and Broadway	6	8
Priest and Broadway	10	8
Thomas and 44th Street	7	10
Stonex's Scenario	8	12
Warne's Scenario	9	15
Scottsdale and Thomas	7	14
Dobson and Main	7	9

Running The Model

Once this stage was completed for each intersection condition, it was time to run the model and document the results. For each one of the selected 10 minute periods the corresponding 10 minute volume for the approaches parallel to the camera's field of view were adjusted to an hourly volume. The data relevant to each 10 minute period was keyed into the TEXAS model, both the geometry and driver-vehicle data and the simulation data. The model was run 15 times for each particular case with the replacement of the random number seed for each approach being the only change conducted from one run to the next. For each run a warm-up period of 5 minutes and a simulation period of 10 minutes were used.

The TEXAS output contains a large number of variables. These variables include: the total and average travel time, the averages and maximum length of queue on each inbound lanes, the delay resulting from slowing below xx mph, average queue delay, and average stopped delay. Since the field data measured stopped delay, it was decided to record the stopped delay values produced by the TEXAS model and ignore queue delay and queue length.

The output of the TEXAS model gives extensive results for each movement on each approach as well as summary results for each approach and for the whole intersection. Only the two approaches parallel to the camera's field of view were considered for comparison because the field data from the previous studies were only for those two approaches.

Statistical Tests

The output from the TEXAS model for the left turn and the through movements on the two approaches parallel to the camera's view were compared with the field results from the studies (15, 17, 20) The right turns were excluded because the previous studies (15, 17, 20) emphasized left turn and through movements analyses. Right turn stopped delay was only collected when the near approach had an exclusive right turn lane. Otherwise right turns were not observed due to unimportance and in some cases due to physical obstacles near the intersection which obstructed the viewer's sight. Therefore for the purpose of this study the right turns were neglected in the comparison process.

The comparison procedure required the use of statistical tests to analyze the data and come to a conclusive decision. The objective of the required test is to make a decision on the presence of a significant difference between the output from the TEXAS model and the field data results. This statistical evaluation of data ensures that within a reasonable level of significance the conclusions reached are valid.

Paired Data t-Test

An appropriate test is that for the inferences about two means. For this research each measurement in one sample (simulation results) is matched with a particular measurement in the other sample (field results). This means that the random samples come from one population and therefore they are dependent random samples. The analysis uses the Student t-test because of the fact that the sample size is less than 30. Due to these conditions, the appropriate test to be used is the paired data t-test.

The null hypothesis tests that the difference between the pair means equals a value Do. For this test to be valid it is assumed that the population of the mean differences follow a normal distribution and the variance is unknown (16). The generalized form of the paired data t-test is given as follows:

Null Hypothesis:	Ho: $\mu d = Do$
Alternate Hypothesis	Ha: $\mu d > Do$
	Ha: $\mu d < Do$
	Ha: $\mu d \neq Do$
The test statistic:	T.S.: $t = \frac{\bar{d} - D_o}{S_d/\sqrt{n}}$

where: $\bar{d}$ = sample mean of the n differences

Sd = sample standard deviation of the n differences

Rejection Region:

for level of significance = α (alpha)

degrees of freedom (df) = n-1

	reject H_0 if	$t > t_\alpha$;
or	reject H_0 if	$t < -t_\alpha$;
or	reject H_0 if	$\lvert t \rvert > t_\alpha/2$.

For this study the null hypothesis (Ho) states that the mean of the differences equals zero. The alternate hypothesis (Ho) states that the mean difference does not equal zero. Therefore the value of Do equals zero and the third rejection region is applicable. The value of alpha, which is the level of significance, was set to 0.05 for all the tests that were conducted.

For each intersection condition the comparison was conducted for the left turn and through movements separately for each of the two approaches parallel to the camera's field of view. If the conclusion obtained from the test is a rejection for that movement, it means that the sample mean for the n differences (d) does not equal zero for the specified level of significance, which is 0.05. In other words the simulation results are significantly different from the field results. On the other hand if the conclusion is not to reject the null hypothesis then it is required to conduct a β-test (beta test) to conclude if the null hypothesis is accepted.

Beta Test

The symbol ,B is used for the probability of type II error. A type II error occurs if the null hypothesis is accepted when in actual fact it is false. The β-test is required to find out the probability of accepting the null hypothesis H_0 which is 1-β. The general equation used to obtain β for a small sample size and a two-tailed test is given as follows:

$$\beta = P\left[t < t_{\alpha/2} \frac{|\mu_o - \mu_a|}{s / \sqrt{n}}\right]$$

where: μ_o is defined as the hypothesized mean.

μ_a is defined as the actual mean under the research hypothesis.

s is the sample standard deviation.

To find β for the paired data t-test, Do is substituted for μ_0 which in all the conditions tested equals zero. The actual mean μ_a is substituted with $\bar{d}$ which is the calculated mean of the differences and the sample standard deviation s is substituted with S_d. Therefore the formula used is given as follows:

$$t_{(\beta,n-1)} = t_{(\alpha/2,n-1)} - \frac{|D_o - \bar{d}|}{S_d/\sqrt{n}}$$

Using the statistical table of the t-distribution and entering at (n-l) degrees of freedom the value of β is obtained. For this study a β error of 0.25 was recommended as the cut- off point of falsely accepting the null hypothesis. Further readings on these statistical tests and more detailed explanations can be obtained from "An Introduction to Statistical Methods and Data Analysis" (16).

Graphical Representation

The simulated average stopped delay results of the left turn movement and the through movement for each one of the two approaches parallel to the camera's field of view were plotted against their respective field stopped delay results. This process was conducted for each one of the eight intersection conditions and produced a number of scattered points corresponding to the number of 10 minute periods selected for a particular intersection condition. The graph also contained a unit slope line which represented the plotting of the field stopped delay results against itself. This line was used to graphically illustrate how much the simulated stopped delay deviated from the optimum solution.

Afterwards the stopped delays for each movement of each approach parallel to the camera's field of view were grouped together depending on the type of left turn phasing. These were keyed into the SuperCalc 5 spreadsheet and a regression analysis, which is built into the software, was conducted to produce the best linear fit for the data points. SuperCalc 5 was used because of the linear regression capabilities incorporated in the software and because of its advanced graphical features. The scattered data points were again compared with the unit slope line. The purpose of this comparison for the grouped data was to try and conclude if they followed a trend similar to that of the observed data. The objective was to try and find if the line that fits the simulated data points is parallel to the unit slope line for the observed data and if so, by how much is it shifted away from it. A statistical test was conducted on the slope coefficient of the regression line to show if it was parallel to the unit slope line. The calculation procedure for the test was similar to the one previously discussed and if the null hypothesis was not rejected a β-test was conducted. The calculated value of the slope coefficient and its standard error were automatically calculated by the software. The level of significance was set to 0.05 and the β error to 0.25.

The above mentioned graphical representation of the results differs from the proposed plots contained in the initial research proposal. Initially, it was proposed that stopped delay be plotted against traffic volume for both observed and simulated data. The idea was to visually judge whether the two plots were close or far apart. As the project progressed, it became clear that the unit slope plot is a better way of displaying the results than the initial proposed method.

RESULTS AND ANALYSES

In order to display the results in a logical form, the eight intersection conditions are grouped by the type of left turn phasing. This is an appropriate grouping because the validation process emphasized on the type of left turn phasing. The intersection conditions of Alma School and Broadway, Stonex's scenario, Warne's scenario, and Scottsdale and Thomas all had an exclusive/permissive left turn phase. Finally, the intersection conditions of Broadway and Priest, and Dobson and Main had an exclusive left turn phase. The statistical analyses and findings of one intersection only are detailed in the next section; then a summary table is provided for all eight intersection conditions.

Results of Alma School and University

The number of critical 10 minute periods selected were eleven for Alma School and

University. The results obtained from running the TEXAS model 15 times for each 10 minute period are summarized and shown in Table D-3. Each average stopped delay value for the left turn movement and for the through movement is the mean of the 15 runs for that time period.

Examining the results, both the eastbound approach and the westbound approach have similar trends. The mean stopped delay of the eleven time periods for both left turns obtained from the simulation are more than three times the mean stopped delay obtained from the field and shown in the observed column. The left turn standard deviation for the simulation results are 61.5 seconds and 76.2 seconds respectively while the standard deviation for the field results are 15.3 seconds and 13.3 seconds respectively. The through movements have the mean stopped delay for the simulation within 2 seconds of the field results and the standard deviation for the mean stopped delay in the field is at least 4 times greater than in the model. The simulation results show that there is a high variation in the delay between the different time periods for the left turn movement than for the through movement on the same approach. This variation is not that extreme for the observed delay data.

A reason for the wide spread left turn delay results in the model is due to the fact that left turn movements take place when opposing through traffic are outside a conflict region. Therefore the delay results vary depending on the combined effect of the opposing volume and the arrival pattern of the opposing traffic. This explanation is not applicable for the through movement and so the delay results are narrowly spread within a small range. For the left turn movement the delays from the model are high compared to the field delay because the model does not accurately represent driver behavior. The conflict region explanation is more conservative than gap acceptance where a left turn would be made when an appropriate gap occurs in the opposing traffic. Also real world driver behavior tends to be more aggressive than anticipated and depends on many factors.

The data points are graphically represented and are shown in Figures D-3 to D-6. Each figure has the simulated delay data plotted against the observed delay. On the same graph a line that has a slope equal to unity is drawn which represents the plotting of the observed delay data against

Table D-3 - Average Stopped Delay Results For Alma School and University (Permissive Left Turns)

Time of Day	Average Stopped Delay (sec)							
	Eastbound Approach				Westbound Approach			
	Left Turn		Through		Left Turn		Through	
	Sim	Obs.	Sim	Obs.	Sim	Obs.	Sim	Obs
8:35 am	29.8	10.5	14.0	12.4	25.9	36.7	14.4	14.0
8:45 am	33.9	26.0	14.5	11.7	30.7	45.0	14.8	15.5
8:55 am	39.2	15.0	14.4	13.9	35.9	24.5	14.5	17.5
9:40 am	109.7	11.4	15.0	15.9	56.9	19.0	15.3	16.7
10:50 am	113.8	42.0	14.5	18.5	62.8	35.0	15.9	20.0
11:30 am	180.1	24.5	16.1	19.2	179.1	57.7	15.5	13.2
1:50 pm	80.8	32.3	15.0	17.0	109.8	35.0	14.6	13.1
2:00 pm	31.8	14.5	14.2	13.3	50.7	19.2	14.3	11.5
2:45 pm	90.3	33.1	14.5	16.9	90.4	28.0	13.9	11.9
3:50 pm	147.2	48.2	17.0	35.8	222.6	--	16.5	19.2
4:20 pm	187.3	50.8	16.1	16.0	206.5	--	16.5	23.3
Mean Del.	94.9	28.0	15.0	17.3	97.4	33.3	15.1	16.0
Std. Dev.	61.49	15.26	1.00	6.90	76.22	13.29	0.94	3.91

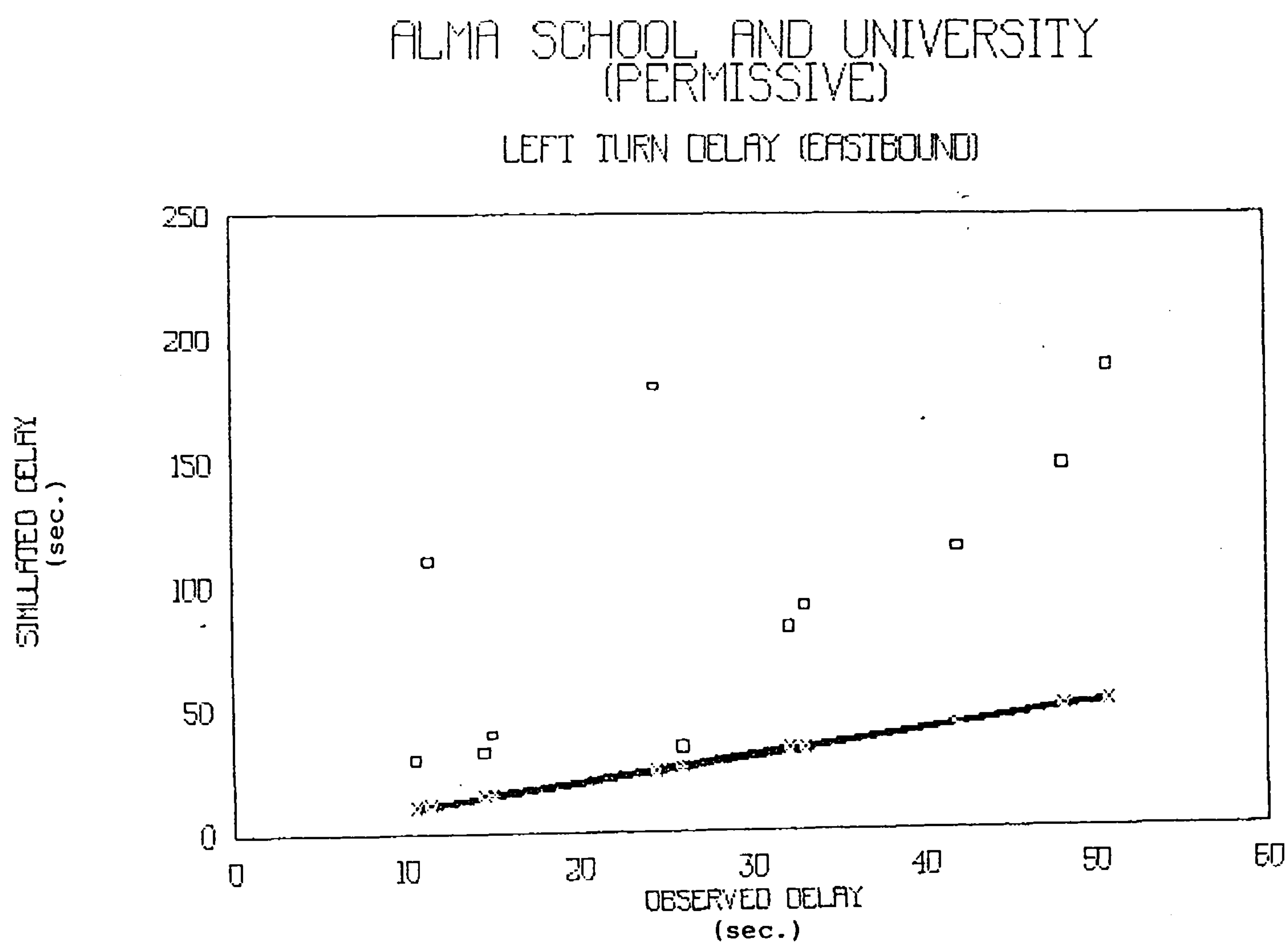


Figure D-3. ALMA SCHOOL AND UNIVERSITY EASTBOUND LEFT TURN RESULTS

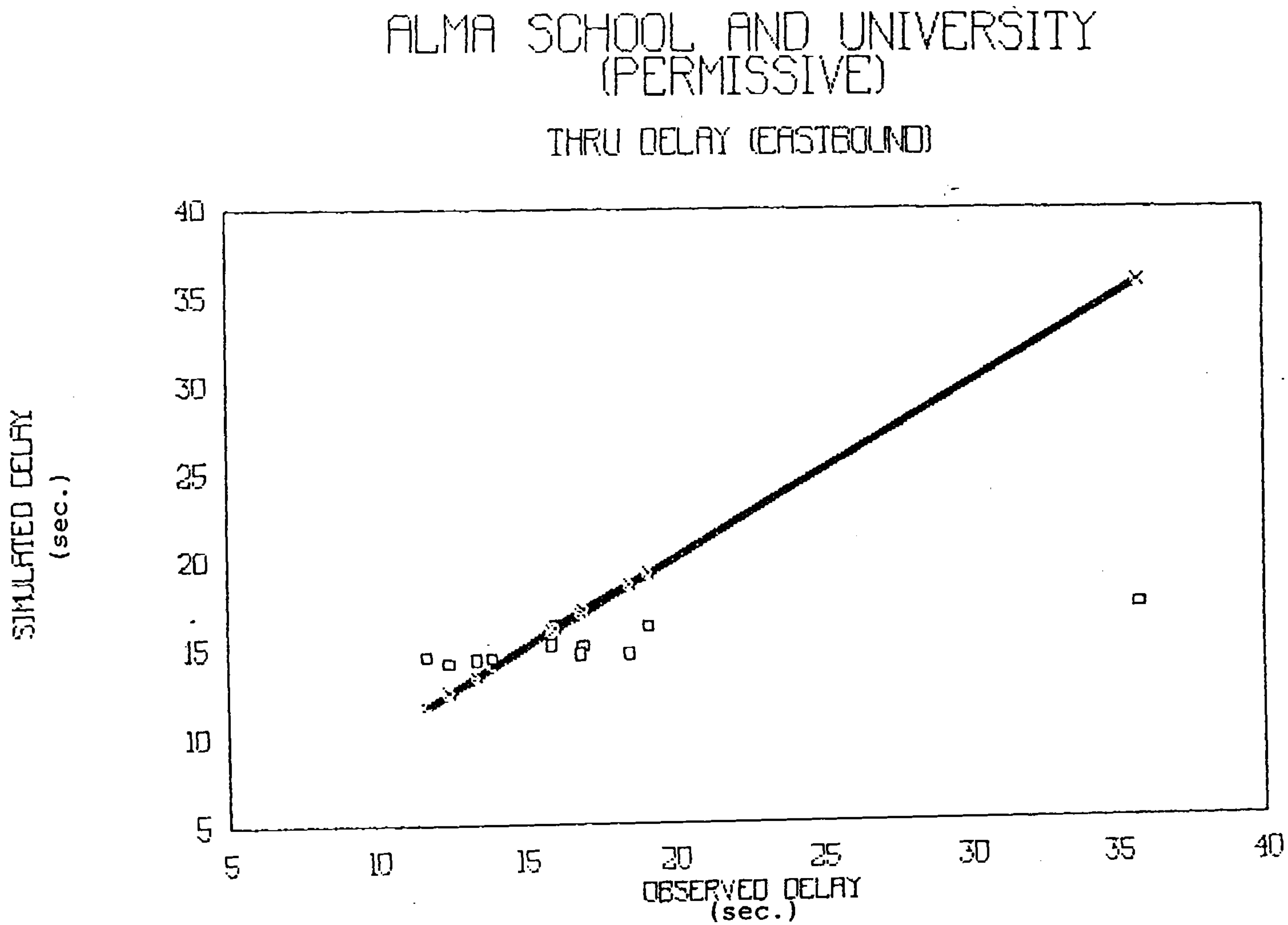


Figure D-4. ALMA SCHOOL AND UNIVERSITY EASTBOUND THROUGH RESULTS

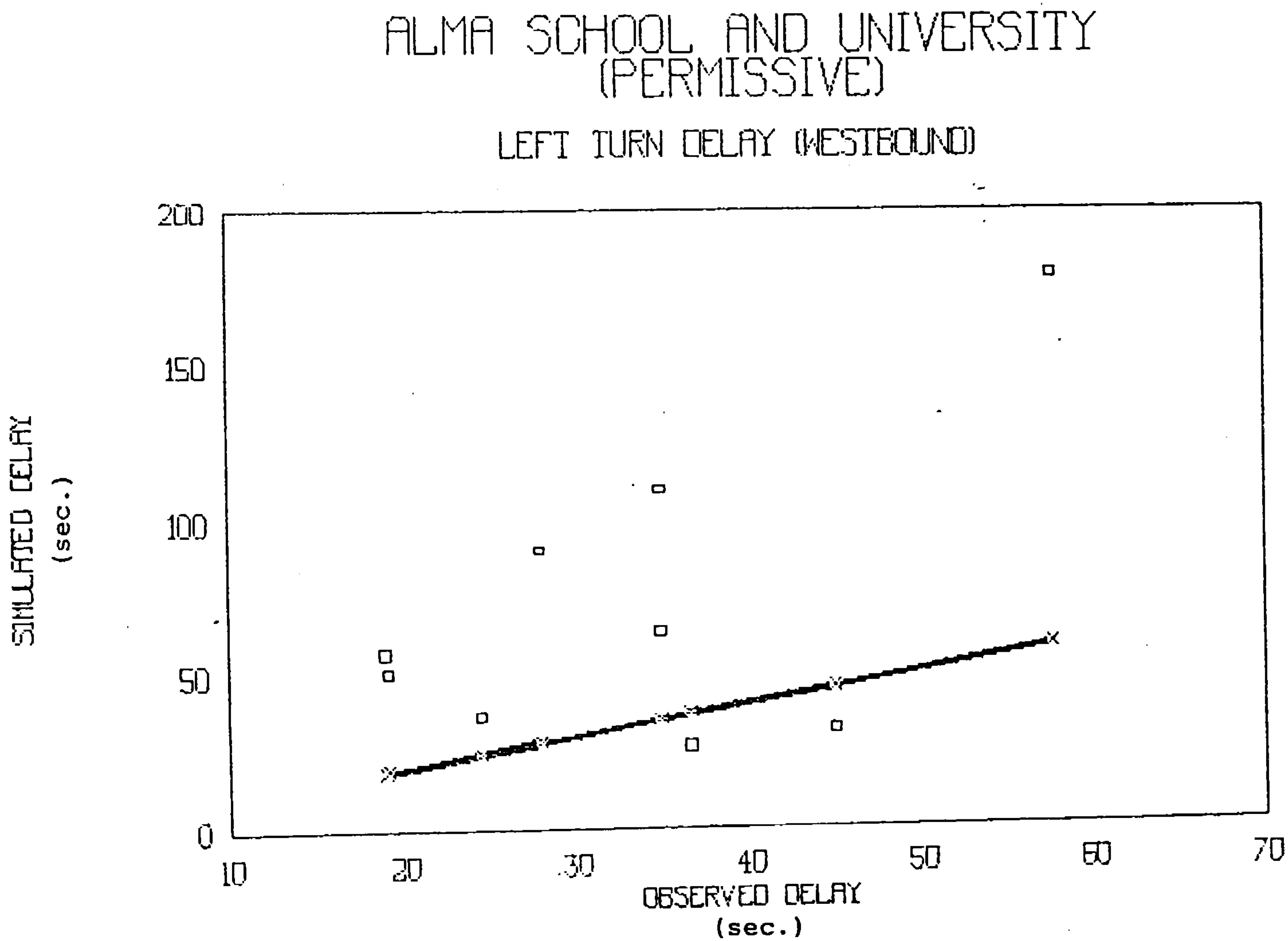


Figure D-5. ALMA SCHOOL AND UNIVERSITY WESTBOUND LEFT TURN RESULTS

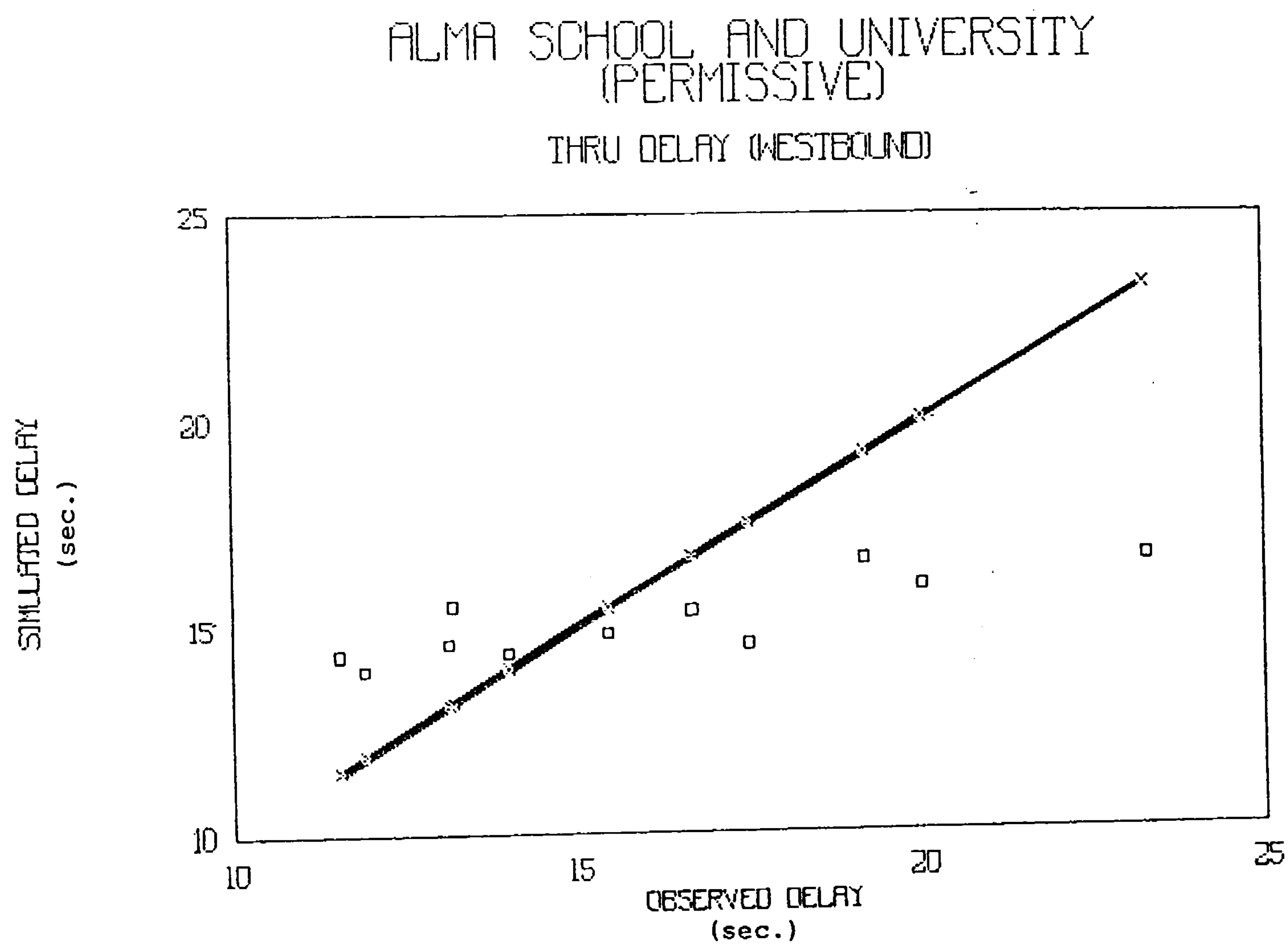


Figure D-6. ALMA SCHOOL AND UNIVERSITY WESTBOUND THROUGH RESULTS

itself. The scatter plot shows how much the simulated delay data deviates from the observed delay data.

Evidence that the simulation model performs well would be shown if the simulated data points fall on or closely around the unit slope line. Figure D-3 shows the results of the eastbound left turn delays with all the data points falling above the unit slope line. Figure D-4 shows the results of the eastbound through delays in which the data points fall above and below the line and are grouped in a small range. Figures D-5 and D-6 show the results for the westbound left turn delays and westbound through delays respectively. The same trends that are noted for the eastbound direction are also present in the westbound direction.

Figures D-3 through D-6 suggest, but do not prove, that the simulation model works well in some cases, and performs poorly in other cases in predicting average stopped delay. To prove or disprove that the model works well, statistical tests were used. The null hypothesis was that the difference between the observed average stopped delay (from field data) and the simulated average stopped delay (TEXAS model) equals zero. The paired data t-test was adopted for the statistical analysis and the results are shown in Table D-4. The mean of the differences and the standard deviation are used to obtain the calculated test statistic t. The results of the statistical analysis show that for a level of significance of 0.05 the null hypothesis was rejected for both eastbound and westbound left turns. The null hypothesis was not rejected for the through movements and on conducting the β-test, the probability of accepting the null hypothesis was greater than 0.75. Therefore it was decided to accept the hypothesis that the difference between the observed means and the simulated means equal zero for both the eastbound and westbound through movements at a confidence level of 0.05. This means that for this intersection, the model is valid only for the through movements and not for the left turn movements. This leads to the belief that the TEXAS model's left turn logic is inconsistent with real world left turn behavior.

The plots of the left turn and through delay results for the remaining seven intersection conditions are documented in Appendix D-2. Also contained in Appendix D-2 are the paired data

Table D-4 - Paired Data t-Test Results for Alma School and University (Permissive Left Turn)

Time of Day	Difference Between Simulated and Observed Delay Results (sec)			
	Eastbound Approach		Westbound Approach	
	Left Turn	Through	Left Turn	Through
8:35 am	19.31	1.62	-10.81	0.36
8:45 am	7.94	2.85	-14.32	-0.67
8:55 am	24.19	0.50	11.37	-3.00
9:40 am	98.29	-0.87	37.94	-1.33
10:50 am	71.77	-4.01	27.76	-4.14
11:30 am	155.62	-3.09	121.41	2.28
1:50 pm	48.52	-1.94	74.77	1.46
2:00 pm	17.31	0.90	31.54	2.79
2:45 pm	57.20	-2.39	62.36	2.03
3:50 pm	99.01	-18.77	--	-2.63
4:20 pm	136.52	0.12	--	-6.75
Mean Difference	66.88	-2.28	38.00	-8.87
Standard Deviation	52.67	6.14	35.74	3.18
t calculated	4.121	-1.231	2.755	-0.911
Conclusion	reject H_0	cannot reject H_0	reject H_0	cannot reject H_0
Probability to Accept $H_0(1-\beta)$	____	0.83	____	0.89

Notes: $n = 11, t_{(0.025,10)} = 2.228$

t-test results.

Results of The Combined Data

The statistical analyses of the second permissive left turn phasing intersection (Thomas and 44th Street) indicated similar results to those of Alma School and University intersection. In both cases it was concluded that the TEXAS model overestimates delay for left turn movements. This finding was previously illustrated in Figures D-3 and D-5 where points were scattered above the unit slope line. It was decided to combine the data of both intersections and attempt to fit a linear regression line for those scattered points. If a straight line parallel to the unit slope line is successfully fitted, then the deviation between the original line and the new line would measure the average deviation between the field data and the TEXAS model results. Linear regression was conducted to fit a line to the scattered data points. The slope coefficient was statistically tested with the null hypothesis stating that the slope coefficient equals 1. If the null hypothesis is accepted than, the regression line through the data points is parallel to the unit slope line, but it is shifted upward at a certain value equal to the value by which the model over estimates delay. Results of the regression analyses are shown in Table D-5. The statistical test conducted to find out if the slope coefficient equals 1 were all rejected except for the left turn delay data for the near side approach. A B-test was conducted and the probability of accepting the null hypothesis that the slope coefficient equals 1 was 0.93. Therefore it is safe to say that the left turn delays for the near side approach obtained from the TEXAS model follow the same trend as the observed left turn delay results for the same approach but with an increased delay of 66.8 seconds.

The regression analysis results of the combined data for exclusive/permissive and exclusive intersections are documented in Appendix D-3.

A summary of all the statistical results for the eight intersection cases and the combined data is shown in Table D-6. The significant conclusion reported for the eight intersection cases means that the simulated mean stopped delays produced by the TEXAS model are significantly different than the mean stopped delays observed in the field at a level of confidence of 95%.

Table D-5 - Regression Analysis Results for Permissive Left Turn Phasing

Parameters	Near Side Approach		Far Side Approach	
	Left Turn	Through	Left Turn	Through
Slope Value	1.132	0.231	1.814	0.227
Sid. Error of Slope	0.266	0.075	0.330	0.066
Intercept Value	66.82	11.72	17.52	11.37
R Squared	0.489	0.331	0.640	
t Calculated	0.495	-10.226	2.467	-11.659
Conclusion	cannot rejcct H_o	rejcct H_o	rejcct H_o	rejcct H_o
Probability to Accept Ho (1-β)	0.93	——	——	——

Notes: H_o: $b_1 = 1$ (slope is unity). H_o:$b_1 = 1$ (slope is not unity)

Table D-6 - Summary of All Statistical Results

Approach		Near Side		Far Side	
		Left Turn	Through	Left Turn	Through
Permissive	Alma School and	S	N.S.*	S	N.S.*
	Thomas and 44th Street	S	S	S	N.S
Exclusive/ Permissive	Alma School and Broadway	S	N.S.*	N.S.*	N.S.*
	Stonex's Scenario	S	S	S	N.S.
	Warne's Scenario	S	N.S.*	S	N.S.*
	Scottsdale and Thomas	S	N.S.*	N.S.	N.S.*
Exclusive	Broadway and Priest	S	N.S.*	S	N.S.*
	Dobson and Main	S	S	S	S
Combined Data	Permissive	N.S.*	S	S	S
	Exclusive/ Permissive	N.S.	S	N.S.	S
	Exclusive	N.S.*	S	N.S.*	S

Note: S -denotes a significant conclusion from the null hypothesis.
N.S -denotes a non-significant conclusion from the null hypothesis.
* -denotes it also passed the β-test criteria.

The combined data includes the three left turn phasing treatments. The permissive left turn treatment combines two intersection results, the exclusive/permissive treatment combines four intersection results, and the exclusive treatment combines two intersection results. The significant conclusion reported for the combined data means that the regression line fitted to the delay data produced by TEXAS has a slope significantly different from unity at a level of confidence of 95%.

Examination of Table D-6 reveals that all the near side left turn delays rejected the null hypothesis that they do not differ from the observed delay, while all the through delays for the combined data were not parallel to the unit slope line.

CONCLUSIONS

The main goal of this study was to test the TEXAS model results against field data, and make recommendations on whether this computer program is a viable tool that the traffic engineer can use in his decision making process. The following conclusions were attained from the numerous simulation runs and statistical analyses:

1. The model was found to have a high variability between the 15 runs for the permissive left turn phasing. This variability decreased for the exclusive/permissive left turn phasing and reached low variability for the exclusive left turn phasing.
2. The model was observed to over estimate delays for left turn traffic for all three signal controller strategies (permissive, exclusive/permissive, and exclusive). The differences between the simulated and observed field data were the greatest for permissive control and it was smaller for exclusive/permissive control and the least for exclusive control.
3 It is believed that the permissive left turn logic can not properly replicate the real world gap acceptance process. Further investigation is needed to review this logic.
4. The results for the through movements were found to be inconsistent. The conclusions reached from the paired data t-test did not follow a noticeable pattern.

The results of the null hypothesis testing, that the difference between the observed mean stopped delay and the simulated mean stopped delay equal zero, was found to be significant in some cases and non significant in other cases. On the other hand the results of the left turn movements consistently gave significant results with few exceptions.

5. Results of the combined data, for testing if the fitted line is parallel to the unit slope line connecting the observed data, were significant for the through movements. Non-significance was evident for the near side left turns implying that there exists a similar trend with the observed data. The far side left turns had mixed results which were significant for the permissive control and not significant for the exclusive control.
6. The non-significant results of the combined data fitted a line that was parallel to the observed data but which was shifted upwards at a certain value equal to the value which the model over estimates delay.
7. It appears that the discharge rate generated internally by the car following model is smaller than the actual rate observed in the field. Appropriate adjustments for the car following parameters may result in agreement between the simulated and field results.

One of the major objectives of this study was to be able to recommend to the traffic engineer an evaluation tool to help in his decision making process. The emphasis was on the ability of the model to adequately predict delays so that it can be used by the traffic engineer to select the best type of left turn phasing for the intersection condition. Presently this selection is difficult because of the model's inability to properly replicate the permissive left turn phasing which is the principal type of phasing that traffic engineers are concerned with.

The model is still useful in giving a better understanding of how the different variables associated with intersection operations interact together. The model could be a powerful tool for traffic engineers to make subjective decisions. This implies that it can be used to conduct theoretical "what if" and "before and after" scenarios for the purpose of making decisions on the variables that affect intersection operation and the effectiveness of one variable as opposed to another. These decisions would become guidelines to the traffic engineer and would not in any way be used for implementation purposes without conducting traditional on site studies.

APPENDIX D-1

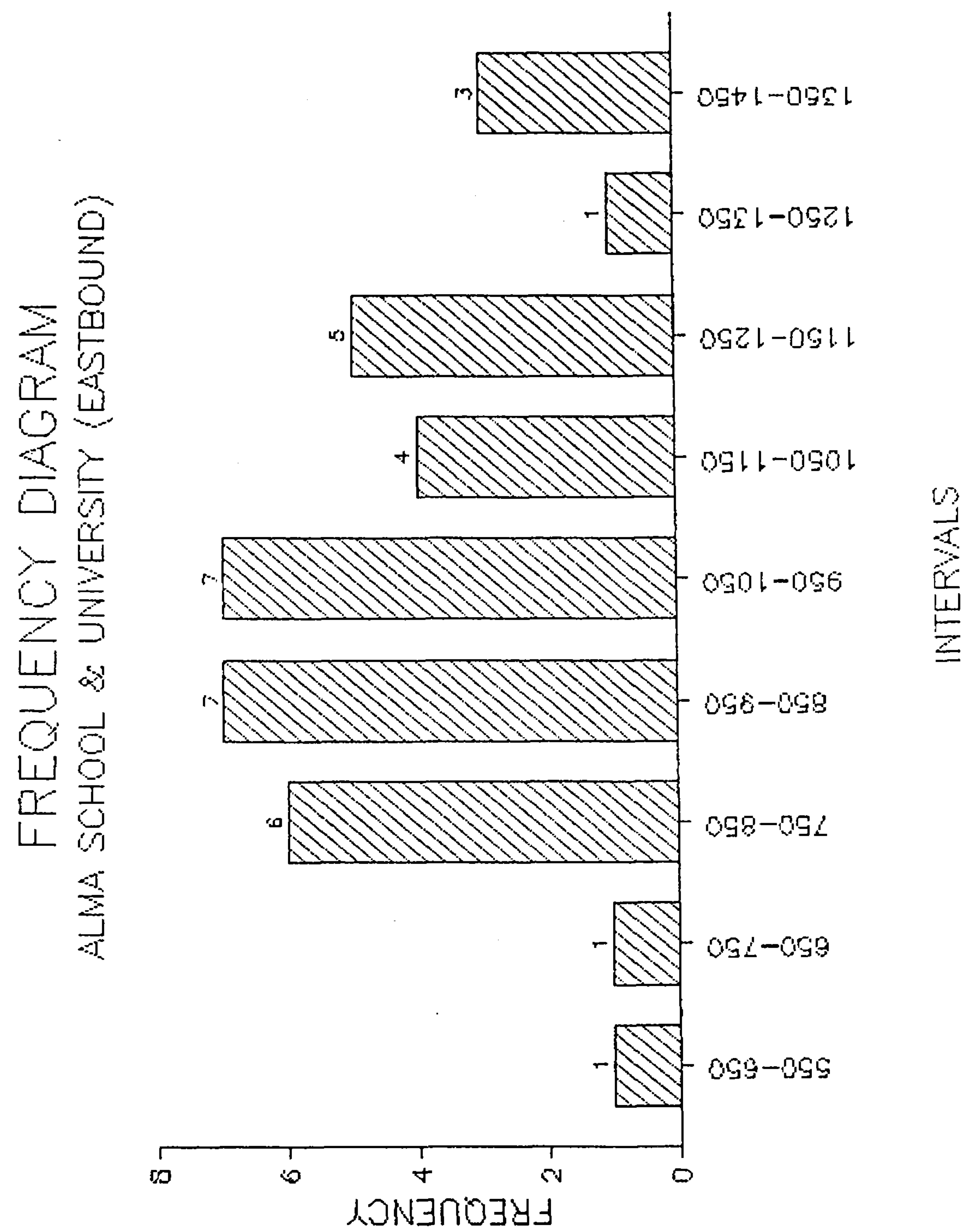
SELECTION PROCESS OF THE CRITICAL 10 MINUTE PERIODS

INTERSECTION : ALMA SCHOOL AND UNIVERSITY (PERMISSIVE LEFT TURNS)

APPROACH : EASTBOUND (LEG 4)

HOURLY VOLUME (VPH)	LEFT TURN VOLUME	PERCENT OF LEFT TURNS	OPPOSING VOLUME (VPH)	CYCLE LENGTH (SEC)	PRODUCT PARAMETER	
588	35	6	942	50	33234	— 1
750	75	10	660	50	49500	— 2
756	30	4	834	50	25220	
762	91	12	786	50	71872	— 3
774	39	5	1218	55	47137	
786	86	11	816	50	70551	
828	50	6	852	50	42327	
834	67	8	864	55	57646	— 4
852	77	9	1134	55	86955	
870	113	13	948	50	107219	— 5
918	46	5	882	55	40484	
930	74	8	1206	55	89726	
948	76	8	1278	55	96924	— 6
948	66	7	1464	55	97151	
948	85	9	918	55	78324	
966	87	9	864	55	75116	
978	39	4	1044	55	40841	
1020	82	8	1128	55	92045	
1020	92	9	966	55	88679	
1032	62	6	1098	55	67988	
1038	73	7	1026	55	74549	
1038	93	9	996	55	93046	— 7
1062	64	6	1026	55	65377	
1086	98	9	954	55	93244	
1092	66	6	966	55	63292	
1104	155	14	918	55	141886	— 8
1158	127	11	1158	55	147506	— 9
1164	93	8	1038	55	96659	
1194	72	6	1134	55	81240	
1224	73	6	1188	55	87247	
1248	112	9	984	55	110523	
1266	114	9	1266	55	144248	— 10
1356	108	8	1245	55	135058	
1422	114	8	1245	55	141631	— 11
1428	100	7	1194	55	119352	

FREQUENCY	TABLE
550-650	1
650-750	1
750-850	6
850-950	7
950-1050	7
1050-1150	4
1150-1250	5
1250-1350	1
1350-1450	3

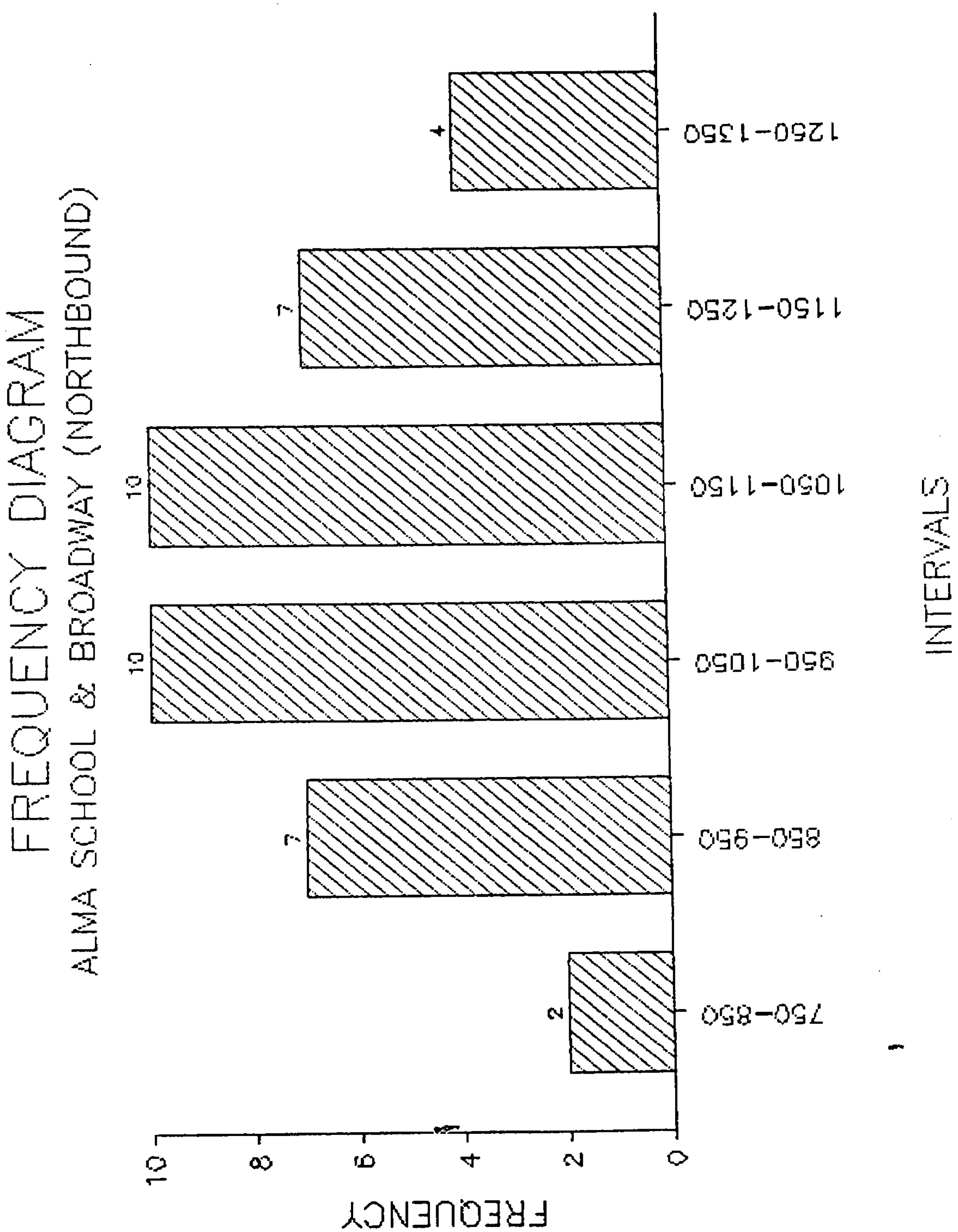

FREQUENCY DIAGRAM
ALMA SCHOOL & UNIVERSITY (EASTBOUND)
FREQUENCY
0
2
4
6
8
INTERVALS
550-650
650-750
750-850
850-950
950-1050
1050-1150
1150-1250
1250-1350
1350-1450
1
1
6
7
7
4
5
1
3

INTERSECTION : ALMA SCHOOL AND BROADWAY (EXCLUSIVE/PERMISSIVE LEFT TURNS)

APPROACH : NORTHBOUND (LEG 3)

HOURLY VOLUME (VPH)	LEFT TURN VOLUME	PERCENT OF LEFT TURNS	OPPOSING VOLUME (VPH)	CYCLE LENGTH (SEC)	PRODUCT PARAMETER	
765	107	14	900	148.5	96390	
786	165	21	1128	148.5	186188	— 1
858	129	15	858	148.5	110425	
864	147	17	774	148.5	113685	
888	186	21	1050	148.5	195804	— 2
912	128	14	792	148.5	101123	
930	140	15	990	148.5	138105	
942	170	18	930	148.5	157691	
948	142	15	864	148.5	122861	
954	153	16	930	148.5	141955	
954	181	19	924	148.5	167484	
954	105	11	954	148.5	100113	
960	154	16	1128	148.5	173261	
978	137	14	888	148.5	121585	
996	100	10	804	148.5	80078	
1002	160	16	1434	148.5	229899	— 3
1014	172	17	930	148.5	160313	
1044	188	18	810	148.5	152215	— 4
1044	146	14	870	148.5	127159	
1068	171	16	1158	148.5	197879	
1068	182	17	1344	148.5	244017	
1080	173	16	978	148.5	168998	
1086	185	17	1134	148.5	209359	
1098	285	26	1236	148.5	352853	— 5
1104	188	17	1098	148.5	206073	
1116	246	22	1116	148.5	274000	
1134	91	8	1446	148.5	131181	
1140	160	14	1266	148.5	202054	
1146	218	19	954	148.5	207724	
1152	207	18	1446	148.5	299843	— 6
1158	151	13	1572	148.5	236649	
1158	139	12	1512	148.5	210108	
1164	128	11	1140	148.5	145966	
1170	140	12	1350	148.5	189540	
1194	96	8	1452	148.5	138695	
1194	215	18	1308	148.5	281115	— 7
1272	191	15	1140	148.5	217512	
1290	232	18	930	148.5	215946	— 8
1320	198	15	984	148.5	194832	
1332	173	13	918	148.5	158961	

FREQUENCY	TABLE
750-850	2
850-950	7
950-1050	10
1050-1150	10
1150-1250	7
1250-1350	4


FREQUENCY DIAGRAM
ALMA SCHOOL & BROADWAY (NORTHBOUND)
FREQUENCY
0
2
4
6
8
10
2
7
10
10
7
4
750-850
850-950
950-1050
1050-1150
1150-1250
1250-1350
INTERVALS

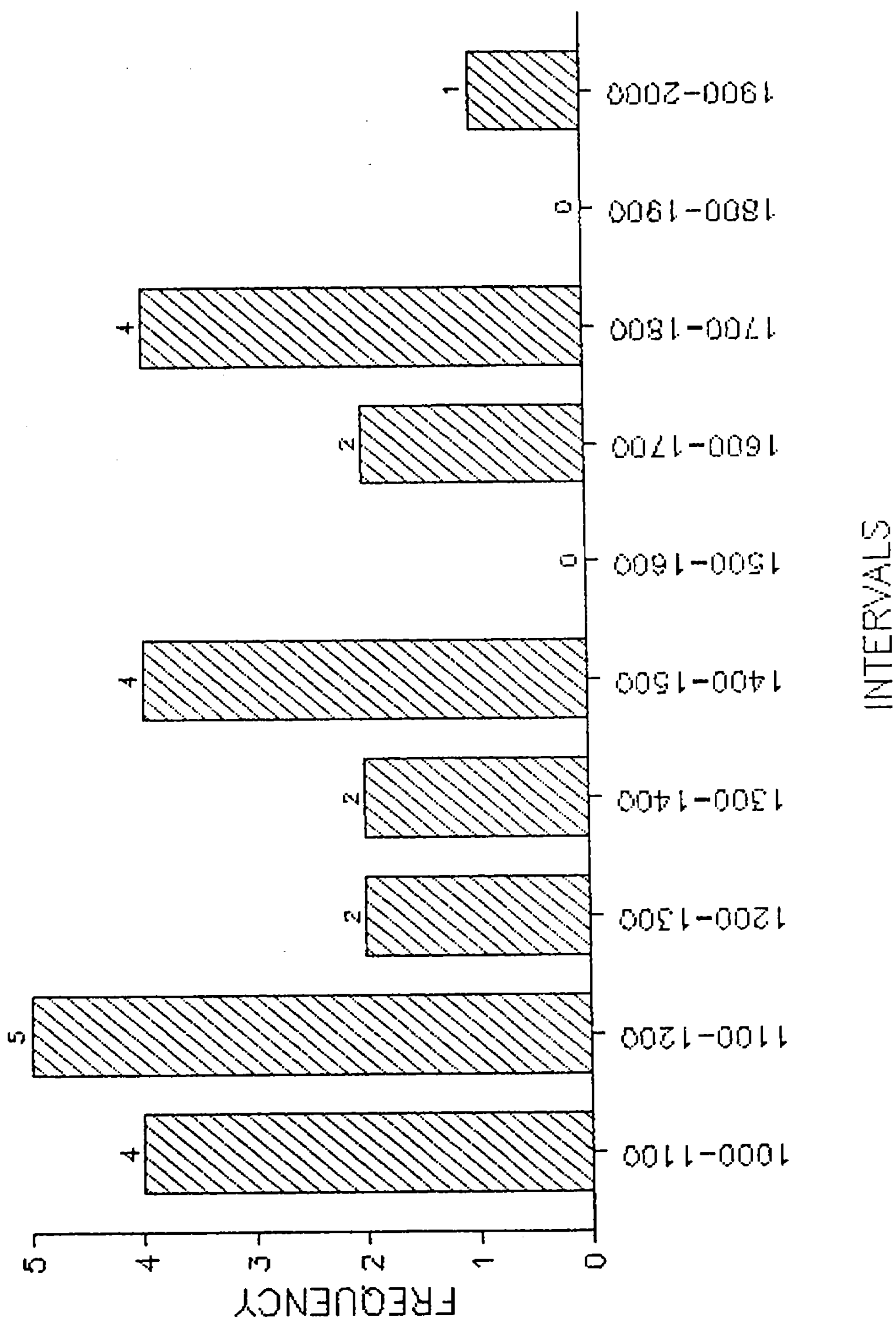
INTERSECTION : BROADWAY AND PRIEST (EXCLUSIVE LEFT TURNS)

APPROACH : EASTBOUND (LEG 4)

HOURLY VOLUME (VPH)	LEFT TURN VOLUME	PERCENT OF LEFT TURNS	OPPOSING VOLUME (VPH)	CYCLE LENGTH (SEC)	PRODUCT PARAMETER	
1014	142	14	936	129	132875	
1020	122	12	1218	129	149083	
1062	181	17	876	129	158153	
1080	194	18	1302	129	253109	— 1
1128	113	10	966	129	108965	
1164	163	14	1152	129	187730	
1188	119	10	1488	129	176774	
1188	131	11	1224	129	159952	
1194	203	17	1062	129	215565	— 2
1230	123	10	1110	129	136530	
1278	217	17	1320	129	286783	— 3
1386	194	14	1290	129	250312	— 4
1392	153	11	1194	129	182825	
1428	157	11	1200	129	188496	
1440	130	9	1344	129	174182	
1440	230	16	936	129	215654	— 5
1482	178	12	1164	129	207006	
1644	132	8	1410	129	185443	
1668	217	13	1368	129	296637	— 6
1734	225	13	1566	129	353008	— 7
1734	191	11	1404	129	267799	
1740	174	10	1548	129	269352	
1764	194	11	1494	129	289896	
1920	230	12	1704	129	392602	— 8

FREQUENCY	TABLE
1000-1100	4
1100-1200	5
1200-1300	2
1300-1400	2
1400-1500	4
1500-1600	0
1600-1700	2
1700-1800	4
1800-1900	0
1900-2000	1

FREQUENCY DIAGRAM
BROADWAY & PRIEST (EASTBOUND)



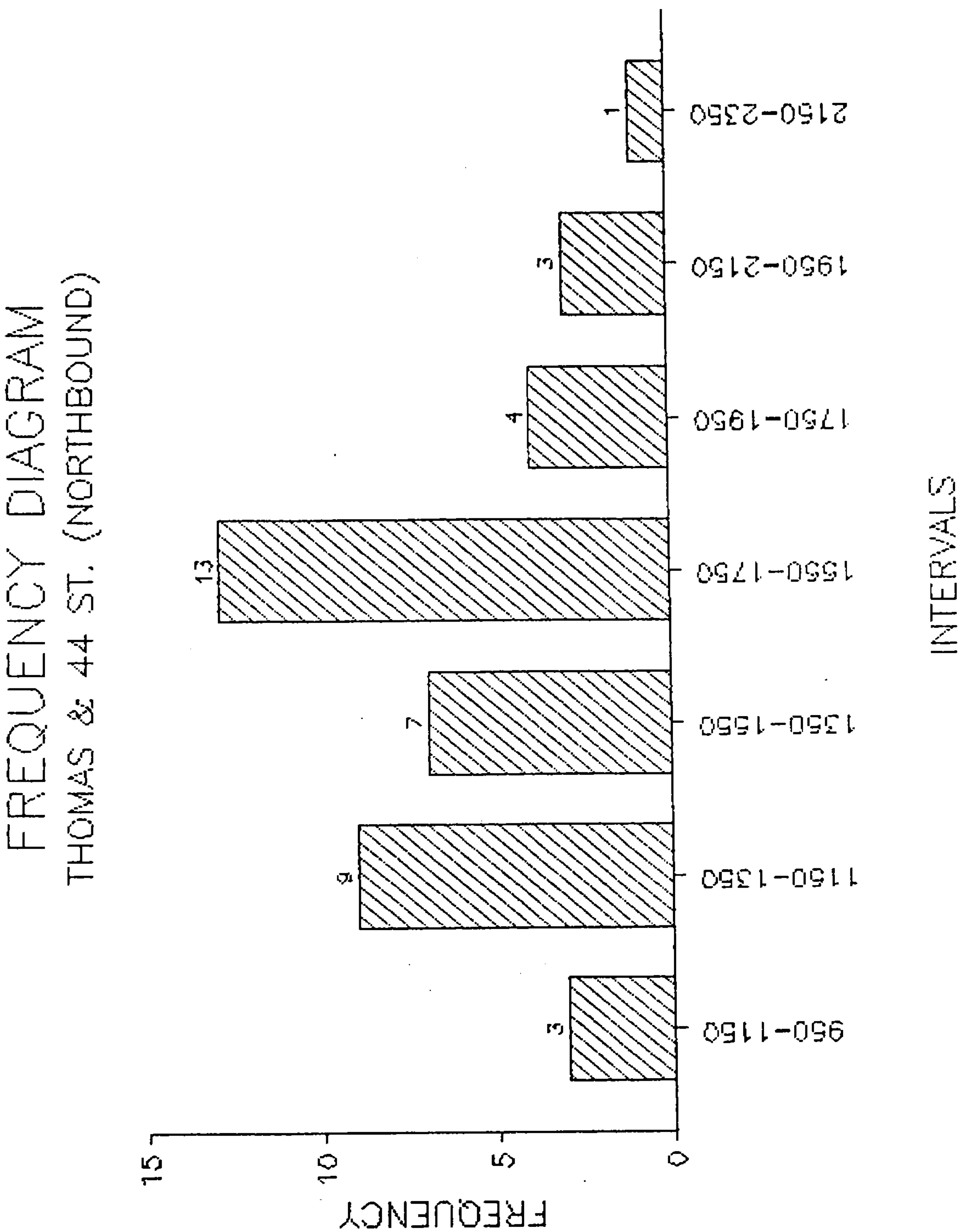
INTERSECTION : THOMAS AND 44 ST. (PERMISSIVE LEFT TURNS)

APPROACH : NORTHBOUND (LEG 3)

HOURLY VOLUME (VPH)	LEFT TURN VOLUME	PERCENT OF LEFT TURNS	OPPOSING VOLUME (VPH)	CYCLE LENGTH (SEC)	PRODUCT PARAMETER	
954	153	16	1392	50	212475	1
1122	123	11	1158	50	142920	
1134	159	14	1014	50	160983	
1194	239	20	1176	50	280829	2
1224	147	12	1806	60	265265	
1254	163	13	1410	50	229858	
1266	152	12	1524	60	231526	
1272	178	14	1380	50	245750	
1278	204	16	1260	50	257645	
1290	142	11	1572	50	223067	
1296	207	16	1260	50	261274	
1338	174	13	1788	60	311005	3
1356	244	18	1524	50	371978	4
1374	165	12	1356	50	223577	
1422	171	12	1458	50	248793	
1428	171	12	1434	50	245730	
1440	202	14	1566	50	315706	
1512	181	12	1638	50	297199	
1536	246	16	1422	50	349471	
1560	187	12	1536	50	287539	
1566	204	13	1410	50	287048	
1566	188	12	1752	50	329236	
1602	208	13	1482	50	308641	
1602	240	15	1404	50	337381	
1614	194	12	1602	50	310275	
1626	211	13	1338	50	282826	
1644	181	11	1566	50	283195	
1662	233	14	1674	50	389506	5
1668	183	11	1650	50	302742	
1698	221	13	1530	50	337732	
1722	207	12	1596	50	329797	
1728	190	11	1434	50	272575	
1836	202	11	1674	50	338081	6
1848	166	9	1632	50	271434	
1890	170	9	1458	55	248006	7
1902	152	8	1620	55	246499	
1974	158	8	1428	55	225510	
2052	205	10	1626	50	333655	8
2124	212	10	1332	55	282917	9
2268	159	7	1476	55	234330	10

FREQUENCY TABLE

950-1150	3
1150-1350	9
1350-1550	7
1550-1750	13
1750-1950	4
1950-2150	3
2150-2350	1

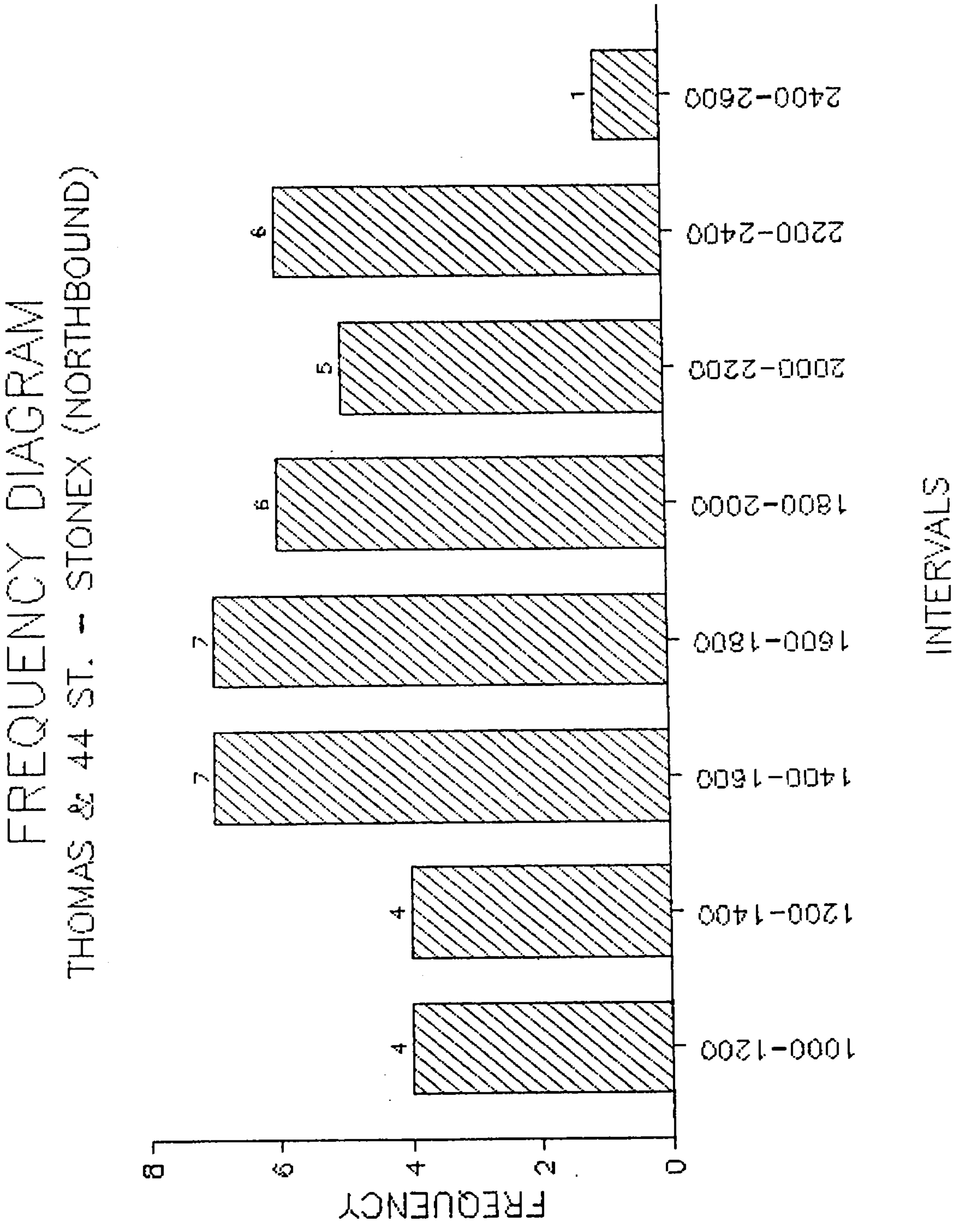


FREQUENCY DIAGRAM
THOMAS & 44 ST. (NORTHBOUND)
FREQUENCY
15
10
5
0
3
9
7
13
4
3
1
950-1150
1150-1350
1350-1550
1550-1750
1750-1950
1950-2150
2150-2350
INTERVALS

INTERSECTION : THOMAS AND 44 ST. (EXCLUSIVE/PERMISSIVE LEFT TURNS)
STONEX
APPROACH : NORTHBOUND (LEG 3)

HOURLY VOLUME (VPH)	LEFT TURN VOLUME	PERCENT OF LEFT TURNS	OPPOSING VOLUME (VPH)	CYCLE LENGTH (SEC)	PRODUCT PARAMETER	
1020	133	13	1446	77	191740	
1086	185	17	1368	95	252560	1
1182	142	12	1350	77	191484	2
1188	214	18	1386	77	296382	
1284	193	15	1332	77	256543	
1320	172	13	1398	77	239897	
1344	202	15	1482	77	298771	3
1362	123	9	1500	95	183870	4
1422	242	17	1488	77	359709	
1452	189	13	1260	77	237838	
1458	175	12	1500	95	262440	5
1500	300	20	1500	77	450000	6
1506	226	15	1578	77	356470	
1536	246	16	1530	77	376013	
1572	236	15	1380	77	325404	
1632	228	14	1530	77	349574	
1650	264	16	1686	77	445104	
1656	282	17	1554	77	437482	
1716	240	14	1380	77	331531	
1722	241	14	1686	77	406461	
1734	260	15	1698	77	441650	
1776	302	17	1704	77	514472	7
1800	288	16	1560	77	449280	
1836	275	15	1536	77	423014	
1944	214	11	1626	77	347704	
1944	272	14	1716	77	467027	
1956	313	16	1530	77	478829	8
1968	256	13	1656	77	423671	
2016	222	11	1626	77	360582	
2046	205	10	1722	95	352321	
2160	238	11	1590	95	377784	9
2190	241	11	1698	77	409048	10
2190	219	10	1686	95	369234	
2208	309	14	1680	95	519322	11
2223	289	13	1632	95	471632	
2298	230	10	1668	95	383306	
2346	188	8	1578	95	296159	
2364	260	11	1620	95	421265	
2370	213	9	1752	95	373702	
2454	245	10	1812	95	444665	12

FREQUENCY	TABLE
1000-1200	4
1200-1400	4
1400-1600	7
1600-1800	7
1800-2000	6
2000-2200	5
2200-2400	6
2400-2600	1


FREQUENCY DIAGRAM
THOMAS & 44 ST. - STONEX (NORTHBOUND)
FREQUENCY
0
2
4
6
8
4
4
7
7
6
5
6
1
1000-1200
1200-1400
1400-1600
1600-1800
1800-2000
2000-2200
2200-2400
2400-2600
INTERVALS

INTERSECTION : THOMAS AND 44 ST. (EXCLUSIVE/PERMISSIVE LEFT TURNS)

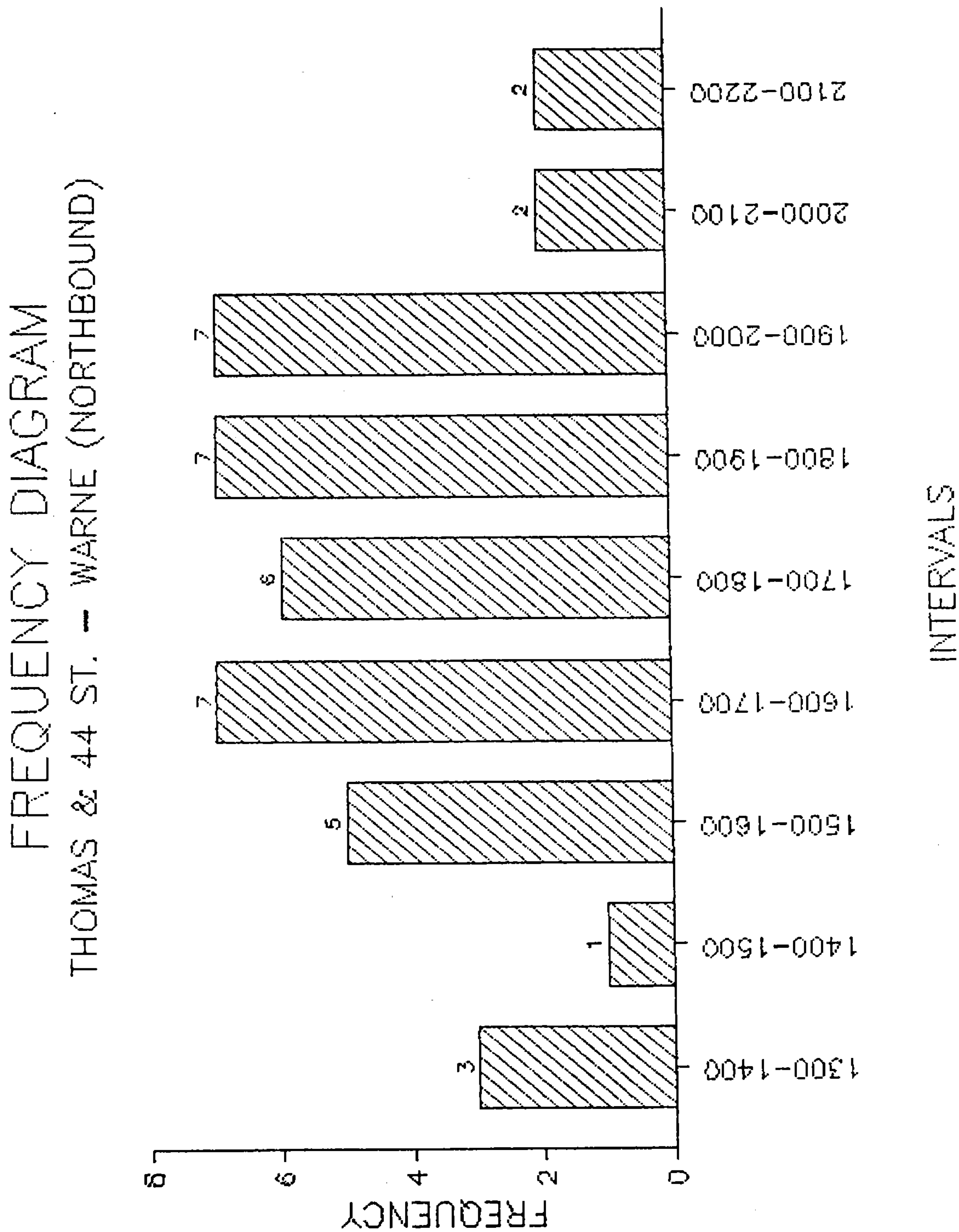
WARNE

APPROACH : NORTHBOUND (LEG 3)

HOURLY VOLUME (VPH)	LEFT TURN VOLUME	PERCENT OF LEFT TURNS	OPPOSING VOLUME (VPH)	CYCLE LENGTH (SEC)	PRODUCT PARAMETER	
1314	171	13	1230	90	210109	
1362	177	13	1284	90	227345	
1362	232	17	1338	90	309801	— 1
1476	148	10	1440	115	212544	— 2
1512	257	17	1140	90	293026	— 3
1530	214	14	1266	90	271177	
1530	245	16	1428	90	349574	
1590	239	15	1482	90	353457	— 4
1596	192	12	1410	90	270043	
1608	273	17	1452	90	396919	
1614	258	16	1392	90	359470	
1620	324	20	1404	90	454896	— 5
1626	179	11	1200	90	214632	
1656	265	16	1320	90	349747	
1662	150	9	1452	90	217190	
1662	233	14	1590	90	369961	
1740	278	16	1614	90	449338	— 6
1752	315	18	1350	90	425736	— 7
1758	264	15	1572	90	414536	
1776	160	9	1578	115	252228	— 8
1788	286	16	1548	90	442852	
1800	270	15	1440	90	388800	
1824	255	14	1698	90	433601	
1836	202	11	1344	90	271434	
1854	278	15	1656	90	460534	
1866	243	13	1530	115	371147	— 9
1872	243	13	1326	90	322695	
1878	282	15	1338	90	376915	
1884	283	15	1626	90	459508	— 10
1920	192	10	1188	115	228096	
1944	292	15	1290	90	376164	
1950	312	16	1602	90	499824	— 11
1950	273	14	1212	90	330876	
1950	234	12	1554	90	363636	
1968	216	11	1386	90	300041	
1980	238	12	1548	115	367805	— 12
2004	321	16	1590	90	509818	— 13
2010	281	14	1428	90	401839	
2118	148	7	1776	115	263310	— 14
2148	236	11	1152	90	272195	— 15

FREQUENCY TABLE

1300-1400	3
1400-1500	1
1500-1600	5
1600-1700	7
1700-1800	6
1800-1900	7
1900-2000	7
2000-2100	2
2100-2200	2

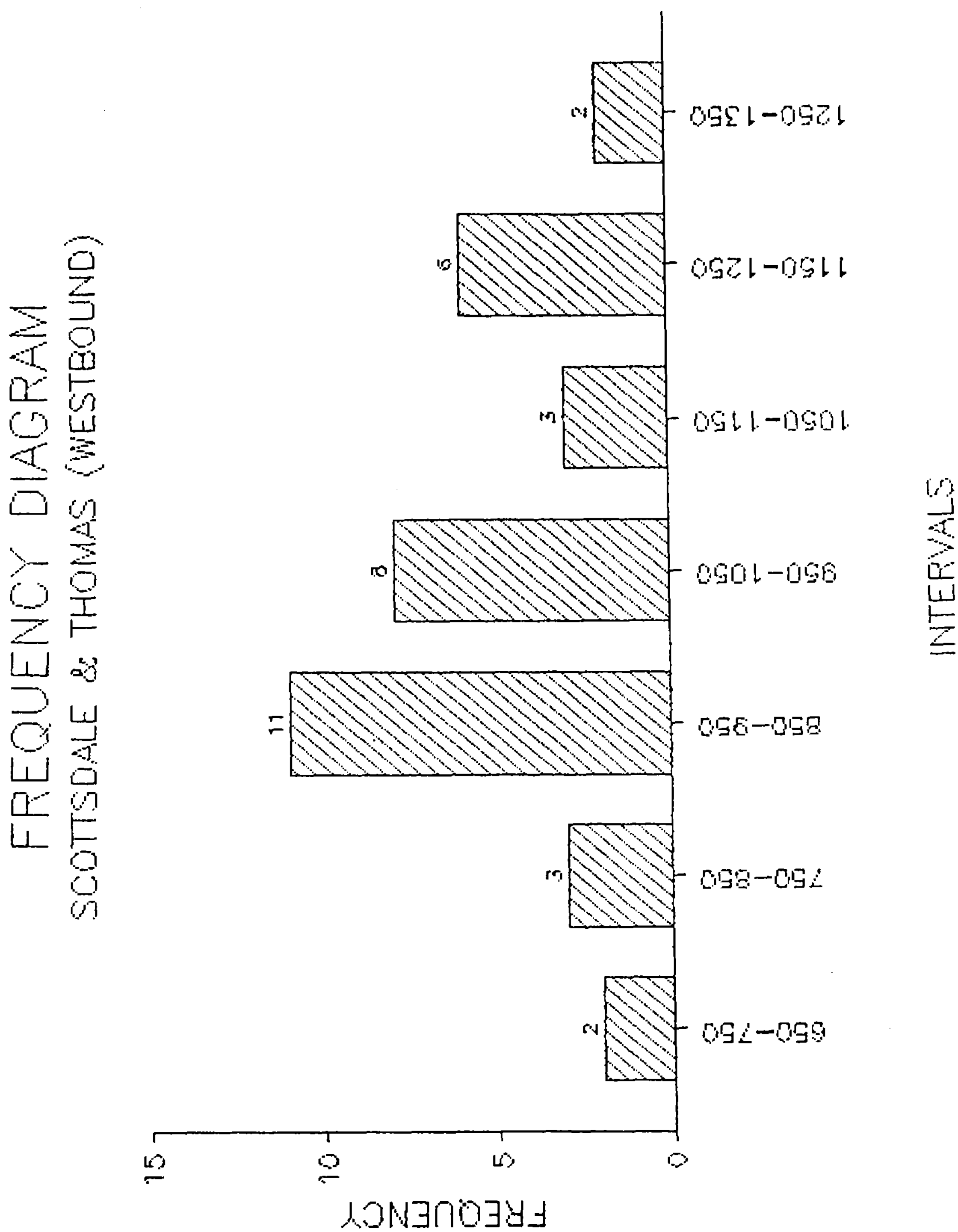

FREQUENCY DIAGRAM
THOMAS & 44 ST. — WARNE (NORTHBOUND)
FREQUENCY
0
2
4
6
8
INTERVALS
1300-1400
1400-1500
1500-1600
1600-1700
1700-1800
1800-1900
1900-2000
2000-2100
2100-2200
3
1
5
7
6
7
7
2
2

INTERSECTION : SCOTTSDALE AND THOMAS (EXCLUSIVE/PERMISSIVE LEFT TURNS)

APPROACH : WESTBOUND (LEG 2)

HOURLY VOLUME (VPH)	LEFT TURN VOLUME	PERCENT OF LEFT TURNS	OPPOSING VOLUME (VPH)	CYCLE LENGTH (SEC)	PRODUCT PARAMETER	Note
696	97	14	1008	94	98220	
750	90	12	1230	94	110700	— 1
816	155	19	1068	94	165583	
834	117	14	906	94	105785	
834	142	17	1404	94	199059	— 2
852	170	20	1134	94	193234	
876	70	8	1002	94A	70220	— 3
876	131	15	1134	94	149008	
894	134	15	918	106	123104	— 4
894	179	20	1416	94	253181	
900	189	21	1446	94	273294	
900	171	19	1380	94	235980	
900	180	20	1236	94	222480	
930	158	17	990	94	156519	
942	141	15	1368	94	193298	
942	207	22	1506	94	312103	— 5
990	149	15	1128	94	167508	
996	219	22	804	94A	176172	— 6
1002	140	14	948	106	132985	— 7
1002	170	17	996	94	169659	
1026	92	9	918	106	84768	
1026	205	20	1338	94	274558	
1044	209	20	1392	94	290650	
1050	231	22	1398	94	322938	— 8
1122	146	13	1350	94	196911	
1122	191	17	1572	94	299843	— 9
1128	203	18	1848	109	375218	— 10
1164	244	21	1476	94	360793	— 11
1176	212	18	1116	94	236235	
1176	153	13	1638	109	250417	— 12
1194	167	14	1596	94	266787	
1194	143	12	1680	109	240710	
1248	150	12	1602	109	239916	
1260	176	14	1590	109	280476	— 13
1350	162	12	1482	94	240084	— 14

FREQUENCY	TABLE
650-750	2
750-850	3
850-950	11
950-1050	8
1050-1150	3
1150-1250	6
1250-1350	2


FREQUENCY DIAGRAM
SCOTTSDALE & THOMAS (WESTBOUND)
FREQUENCY
0
5
10
15
INTERVALS
650-750
750-850
850-950
950-1050
1050-1150
1150-1250
1250-1350
2
3
11
8
3
6
2

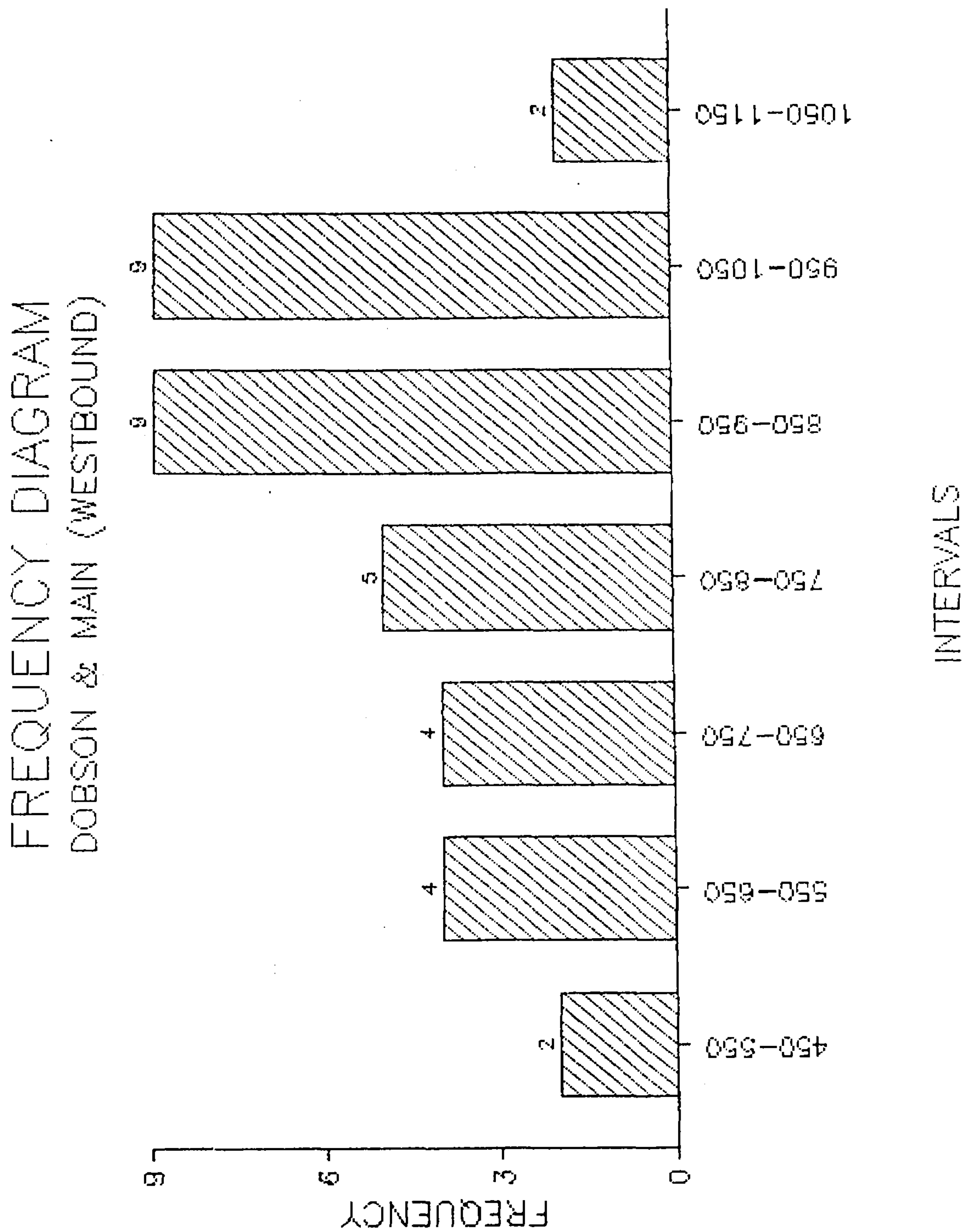
INTERSECTION : DOBSON AND MAIN (EXCLUSIVE LEFT TURNS)

APPROACH : WESTBOUND (LEG 2)

HOURLY VOLUME (VPH)	LEFT TURN VOLUME	PERCENT OF LEFT TURNS	OPPOSING VOLUME (VPH)	CYCLE LENGTH (SEC)	PRODUCT PARAMETER	
492	133	27	492	115	65357	— 1
516	108	21	450	115	48762	
576	156	27	648	115	100777	
582	157	27	564	115	88627	
600	174	29	486	115	84564	
648	188	29	576	115	108242	— 2
660	224	34	738	115	165607	
684	185	27	666	115	122997	
708	248	35	654	115	162061	
732	293	40	894	115	261763	— 3
750	240	32	666	115	159840	
774	286	37	852	115	243996	— 4
780	218	28	918	115	200491	
798	279	35	810	115	226233	
846	254	30	834	115	211669	
870	287	33	1608	115	461657	
876	307	35	1506	115	461740	— 5
882	326	37	1104	115	360279	
906	362	40	1050	115	380520	
912	264	29	1050	115	277704	
936	365	39	1140	115	416146	— 6
942	292	31	996	115	290852	
948	256	27	984	115	251865	
948	284	30	1506	115	428306	
960	365	38	1482	115	540634	— 7
972	311	32	960	115	298598	
990	337	34	1188	115	399881	
996	359	36	1128	115	404456	
1002	321	32	1269	115	406892	
1038	384	37	1050	115	403263	
1044	345	33	972	115	334873	
1044	345	33	966	115	332806	
1044	386	37	1188	115	458901	— 8
1122	426	38	1122	115	478376	— 9
1128	361	32	924	115	333527	

FREQUENCY TABLE

450-550	2
550-650	4
650-750	4
750-850	5
850-950	9
950-1050	9
1050-1150	2

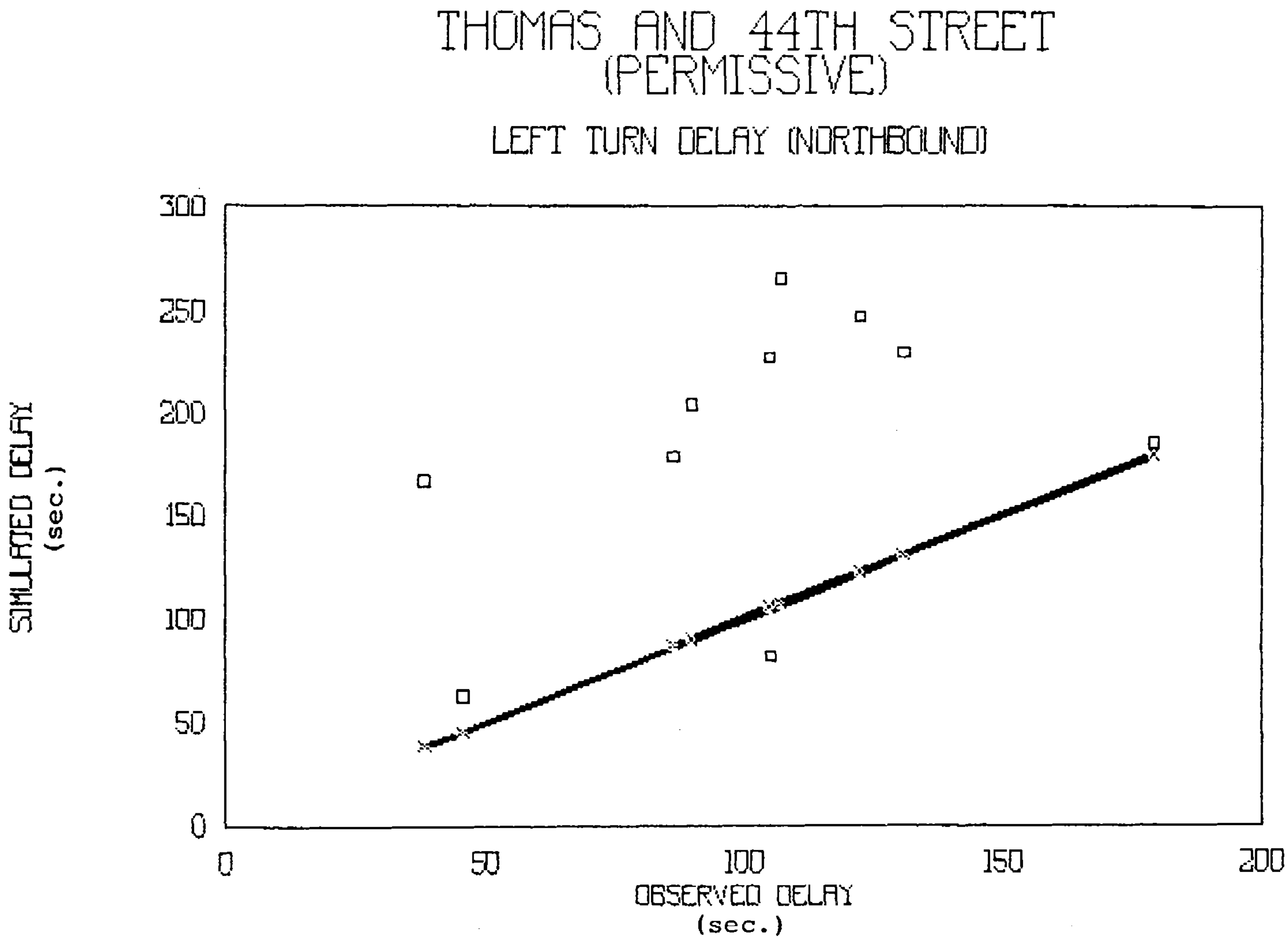

FREQUENCY DIAGRAM
DOBSON & MAIN (WESTBOUND)
FREQUENCY
0
3
6
9
2
4
4
5
9
9
2
450-550
550-650
650-750
750-850
850-950
950-1050
1050-1150
INTERVALS

APPENDIX D-2

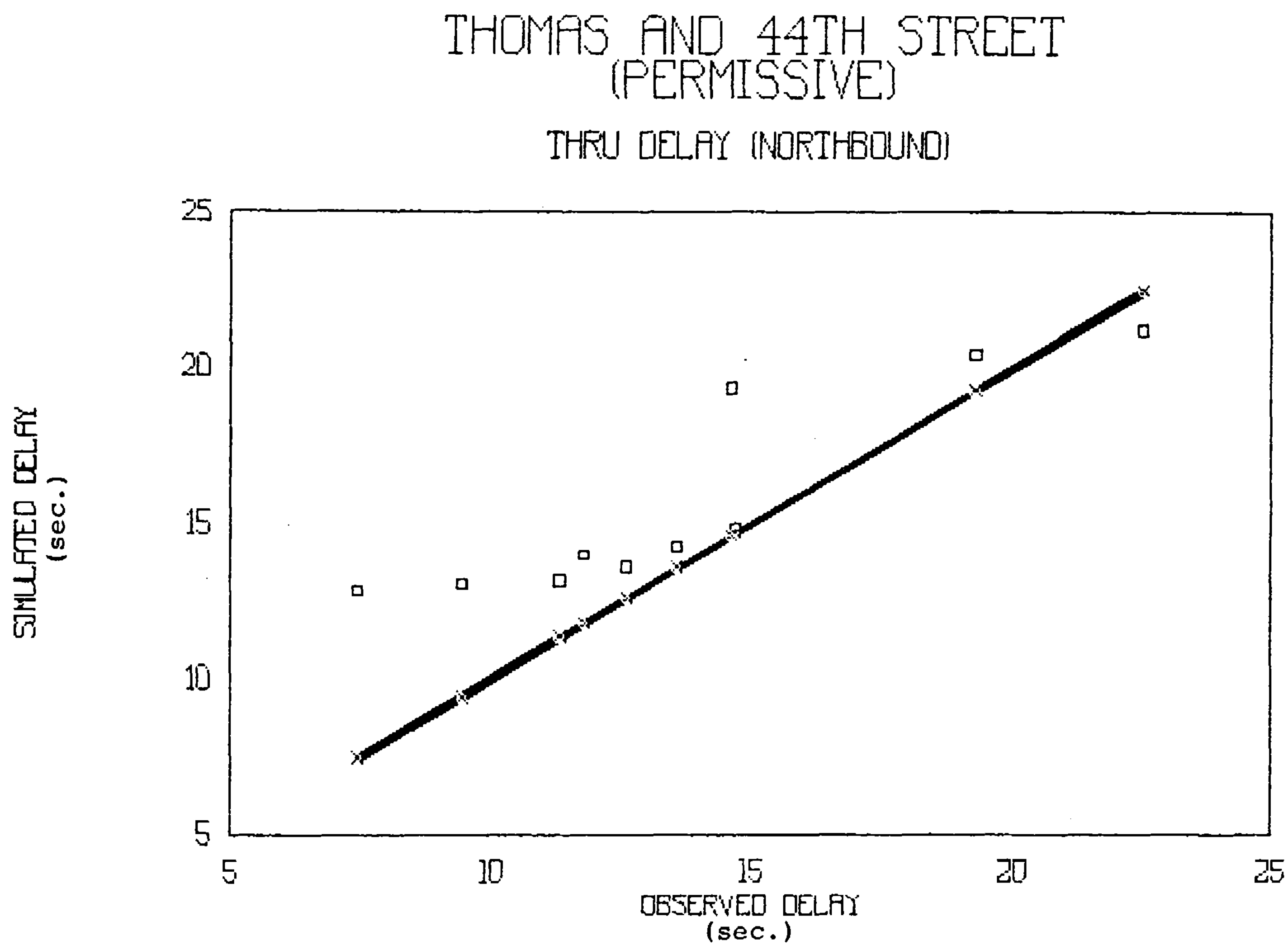
DELAY PLOTS AND PAIRED DATA t-TEST RESULTS

Table - Average Stopped Delay Results For Thomas and 44th Street (Permissive Left Turns)

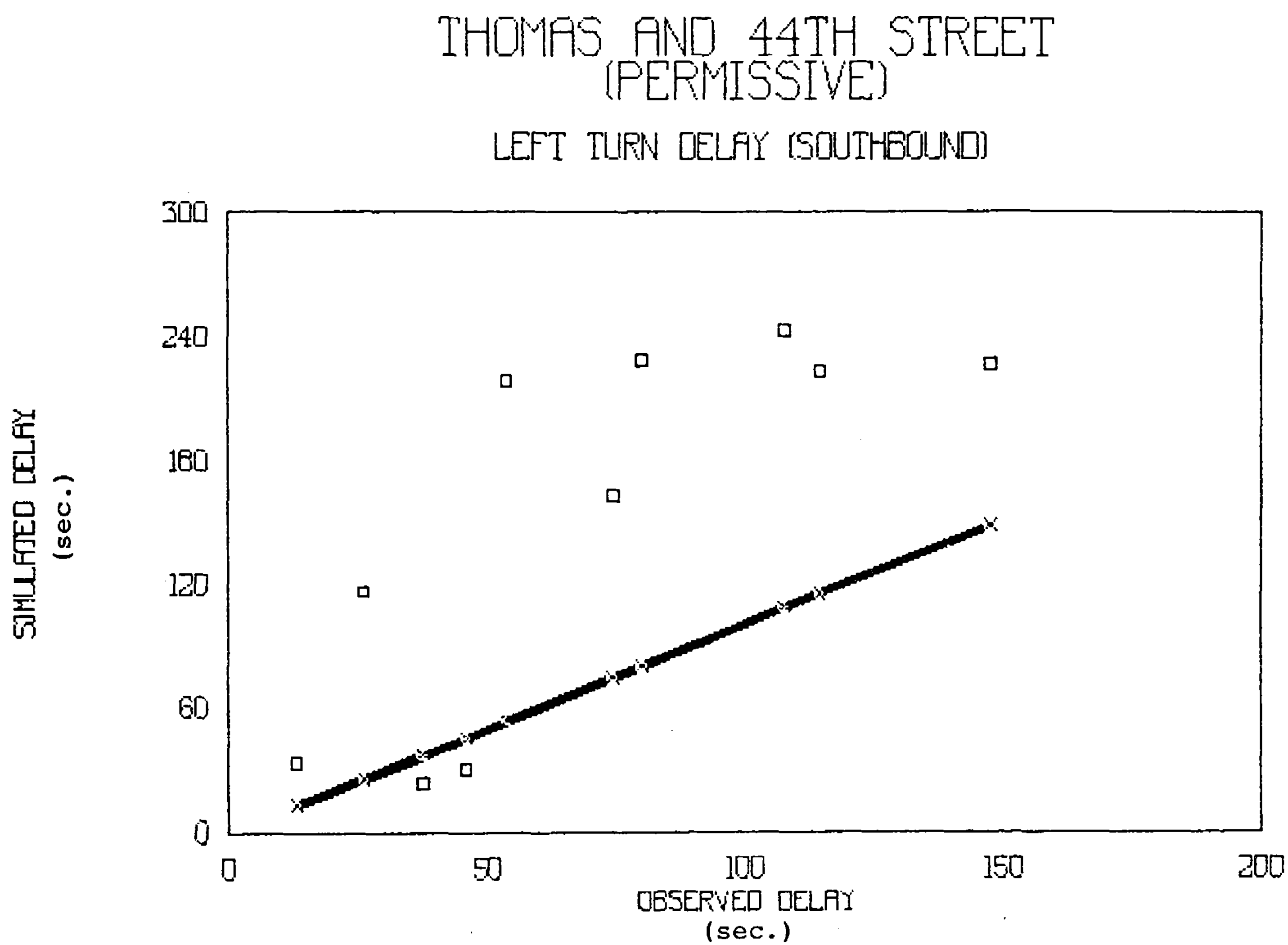
Time of Day	Average Stopped Delay (sec)							
	Northbound Approach				Southbound Approach			
	Left Turn		Through		Left Turn		Through	
	Sim.	Obs.	Sim.	Obs.	Sim.	Obs.	Sim.	Obs.
8:00 am	167.2	38.2	13.1	11.3	29.7	45.8	12.8	14.5
9:25 am	63.2	45.7	12.8	7.4	33.9	13.0	12.9	9.5
9:55 am	81.6	105.2	13.0	9.4	24.0	37.5	12.6	10.6
10:40 am	204.2	89.9	13.6	12.6	116.2	26.1	13.6	11.2
2:00 pm	265.8	107.0	14.2	13.6	162.9	74.3	13.4	13.5
3:00 pm	247.5	122.3	14.0	11.8	228.0	80.0	13.4	13.6
3:40 pm	228.6	130.7	14.8	14.7	222.4	114.4	14.0	13.8
4:00 pm	227.4	104.9	19.3	14.6	242.6	107.6	16.4	16.6
4:20 pm	179.0	86.4	20.4	19.3	218.8	53.8	15.8	10.2
4:40 pm	185.3	178.8	21.2	22.5	225.9	147.4	16.3	13.1
Mean Del.	185.0	100.9	15.6	13.7	150.4	70.0	14.1	12.7
Std. Dev.	70.61	42.75	3.48	4.70	96.57	45.24	1.54	2.36



- Thomas and 44th Street Northbound Left Turn Results



- Thomas and 44th Street Northbound Through Results



- Thomas and 44th Street Southbound Left Turn Results

- Thomas and 44th Street Southbound Through Results

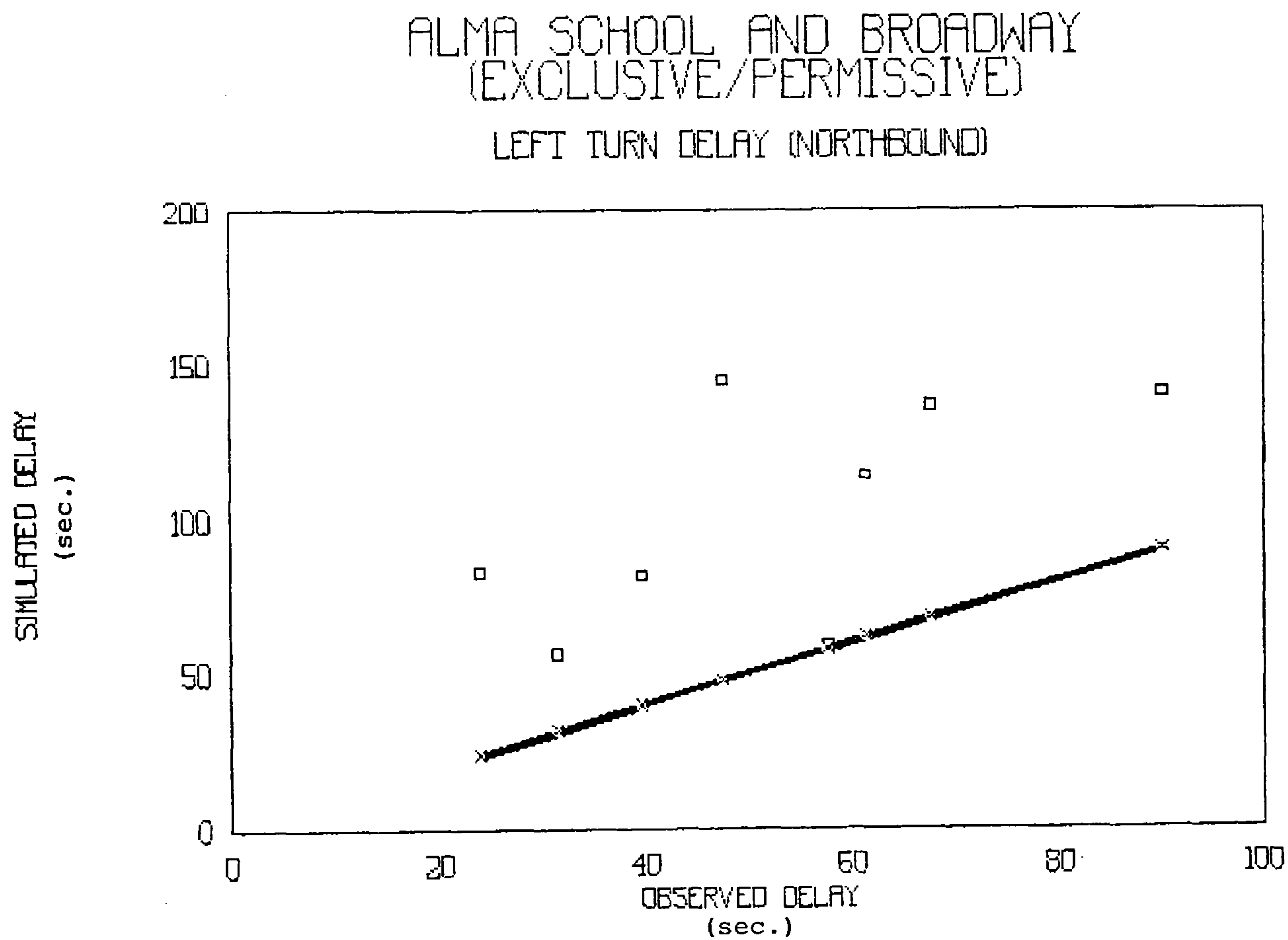
- Paired Data t-Test Results For Thomas and 44th Street (Permissive Left Turns)

Time of Day	Difference Between Simulated and Observed Delay Results (sec)			
	Northbound Approach		Southbound Approach	
	Left Turn	Through	Left Turn	Through
8:00 am	128.99	1.79	-16.09	-1.68
9:25 am	17.55	5.38	20.91	3.36
9:55 am	-23.60	3.59	-13.53	2.04
10:40 am	114.29	1.00	90.08	2.41
2:00 pm	158.83	0.63	88.59	-0.11
3:00 pm	125.18	2.18	147.97	-0.28
3:40 pm	97.89	0.10	107.96	0.15
4:00 pm	122.52	4.69	135.01	-0.24
4:20 pm	92.60	1.15	165.06	5.60
4:40 pm	6.55	-1.34	78.51	3.14
Mean Difference	84.08	1.92	80.45	1.44
Standard Deviation	64.77	2.21	67.87	2.35
t calculated	4.105	2.745	3.748	1.935
Conclusion	reject H_o	reject H_o	reject H_o	cannot reject H_o
Probability to Accept H_o $(1-\beta)$	——	——	——	0.62

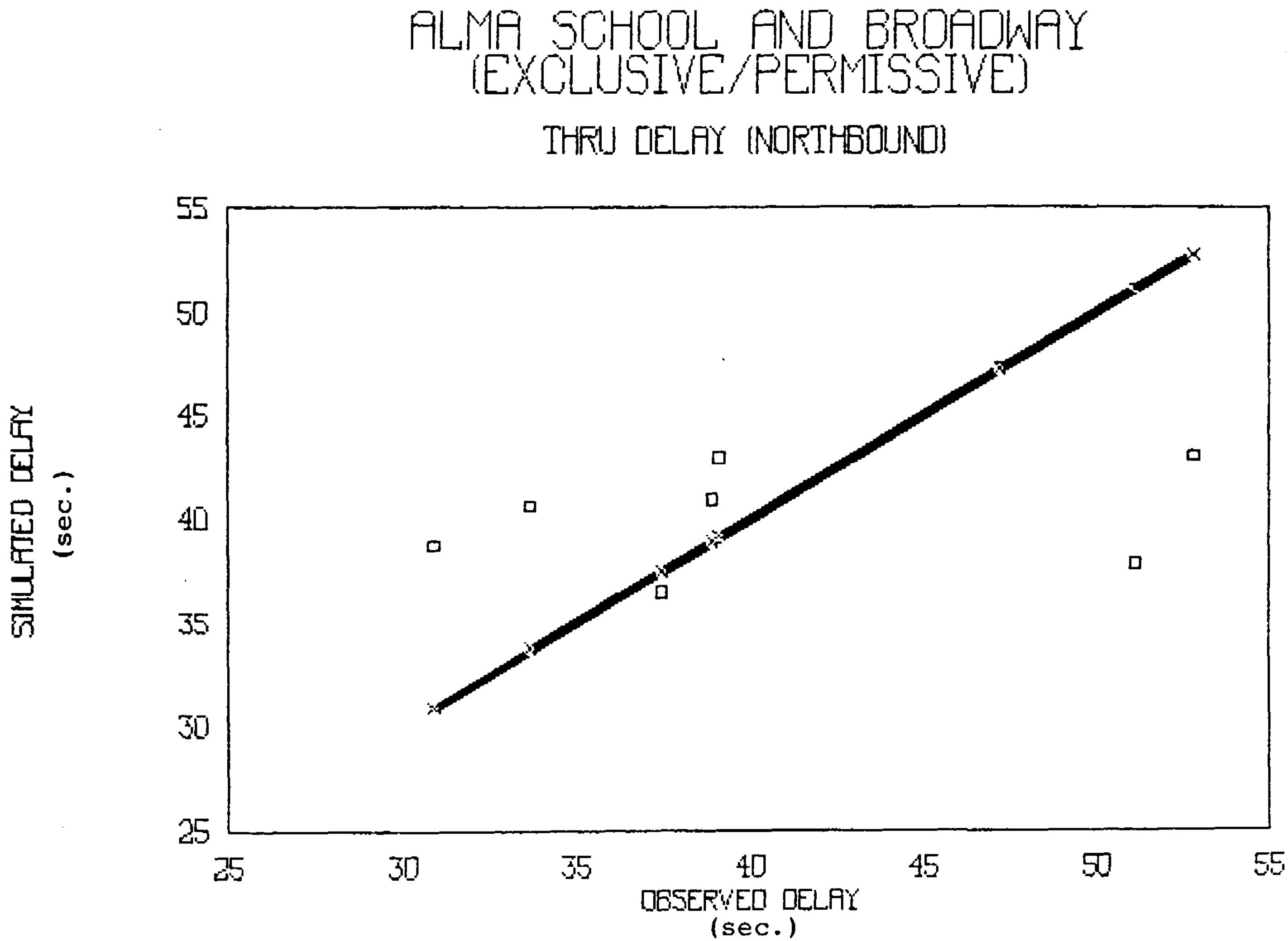
Note : n = 10, $t_{(0.025,9)} = 2.262$

- Average Stopped Delay Results For Alma School and Broadway (Exclusive/Permissive Left Turns)

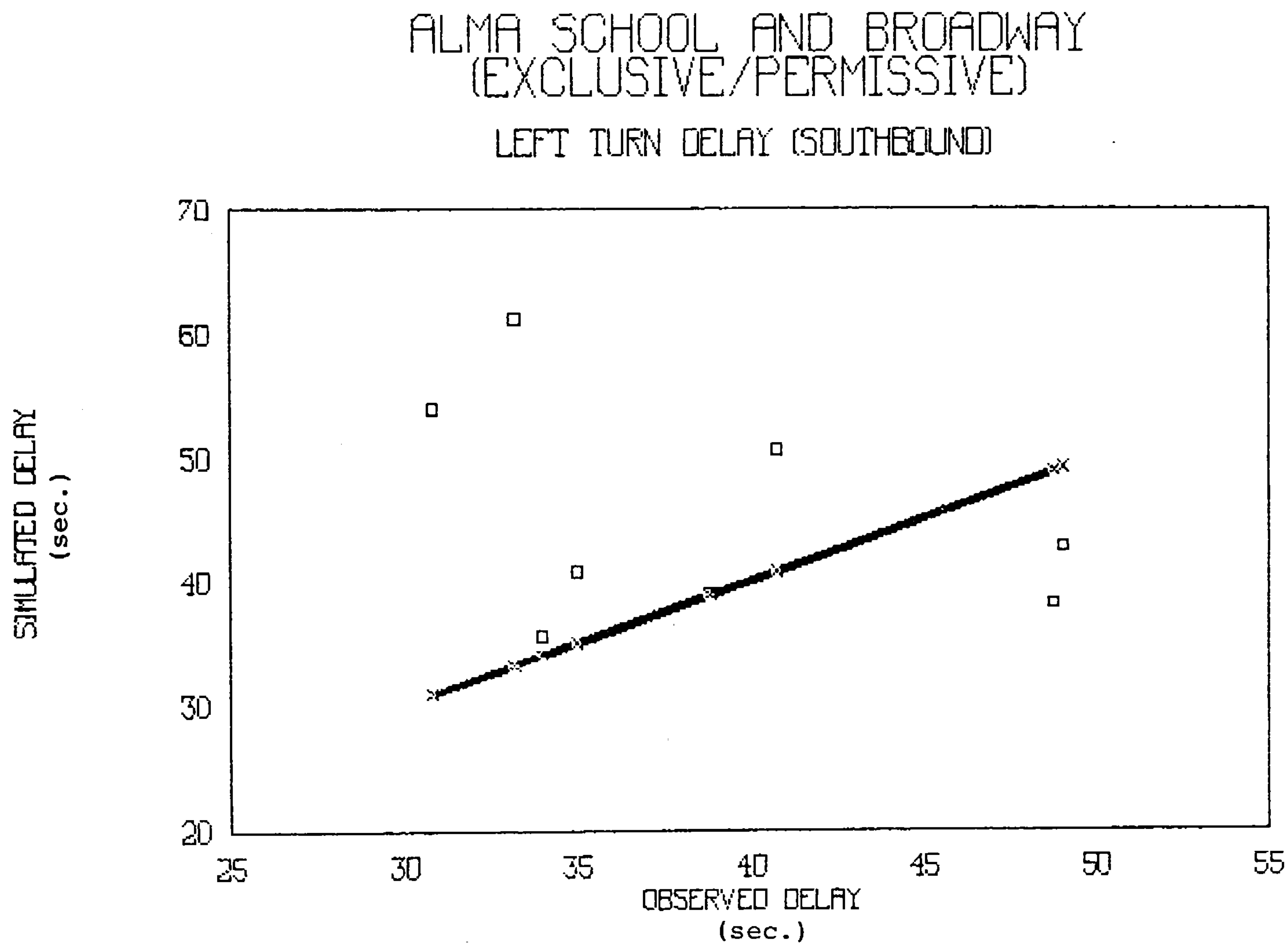
Time of Day	Average Stopped Delay (sec)							
	Northbound Approach				Southbound Approach			
	Left Turn		Through		Left Turn		Through	
	Sim.	Obs.	Sim.	Obs.	Sim.	Obs.	Sim.	Obs.
10:45 am	82.0	39.8	40.7	33.7	42.7	49.0	42.8	39.2
10:55 am	83.0	24.0	40.9	38.9	40.8	35.0	41.2	40.0
1:10 pm	55.7	31.5	38.8	30.9	38.9	38.8	37.9	43.4
2:30 pm	136.9	67.7	37.7	51.1	35.5	34.0	36.1	35.9
2:40 pm	58.5	57.7	36.4	37.5	38.0	48.8	35.7	40.1
3:25 pm	140.9	90.1	43.0	52.8	50.7	40.8	41.7	55.0
4:20 pm	114.2	61.3	43.0	39.1	54.1	30.8	48.7	49.1
5:00 pm	145.5	47.6	47.3	47.2	61.3	33.2	49.6	54.8
Mean Del.	102.1	52.5	41.0	41.4	45.3	38.8	41.7	44.7
Std. Dev.	39.53	22.83	3.71	8.61	9.71	7.45	5.63	7.87



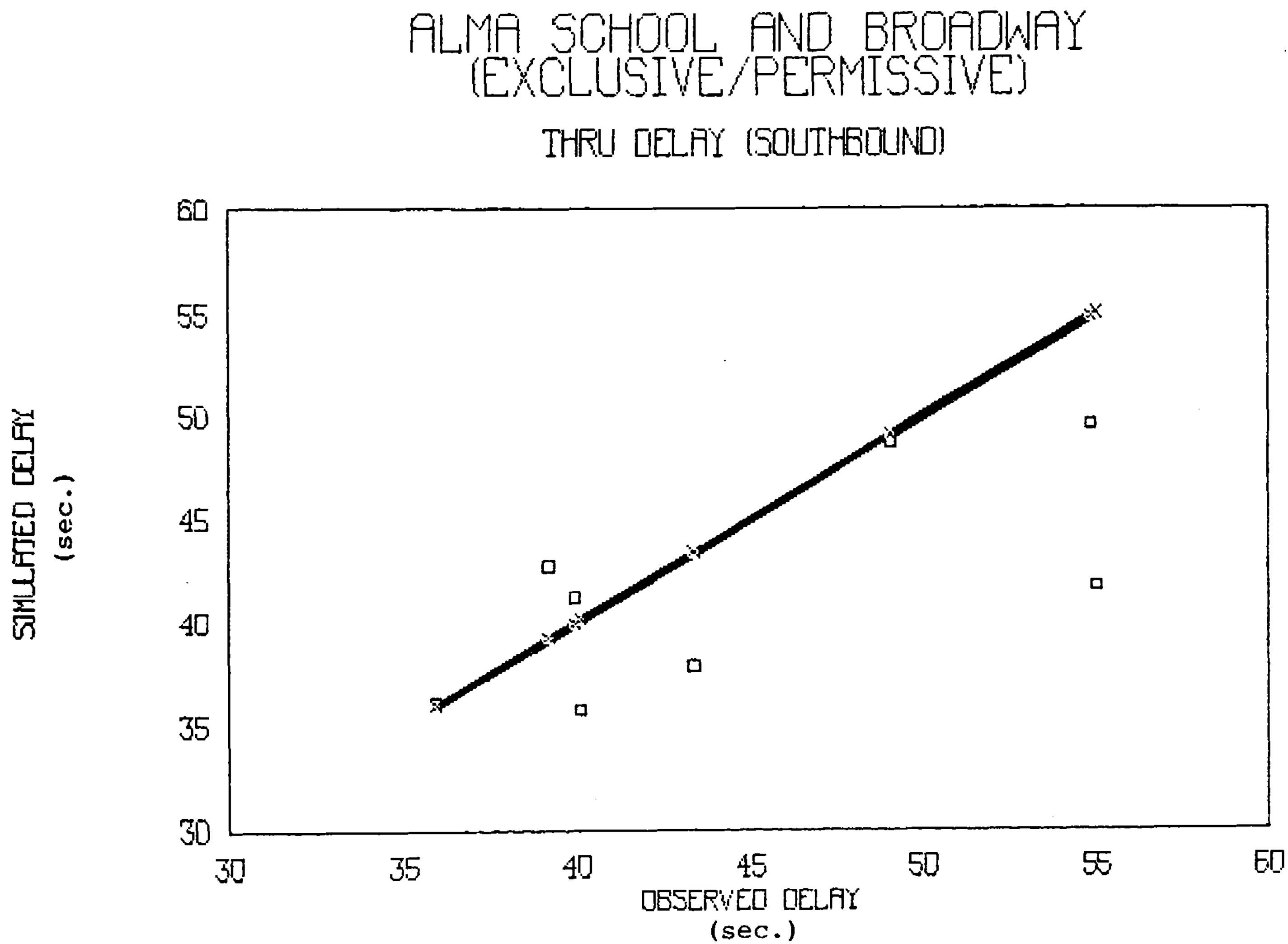
- Alma School and Broadway Northbound Left Turn Results



- Alma School and Broadway Northbound Through Results



- Alma School and Broadway Southbound Left Turn Results



- Alma School and Broadway Southbound Through Results

- Paired Data t-Test Results For Alma School and Broadway (Exclusive/Permissive Left Turns)

Time of Day	Difference Between Simulated and Observed Delay Results (sec)			
	Northbound Approach		Southbound Approach	
	Left Turn	Through	Left Turn	Through
10:45 am	42.26	6.97	-6.31	3.61
10:55 am	58.97	2.01	5.79	1.28
1:10 pm	24.28	7.84	0.09	-5.51
2:30 pm	69.20	-13.37	1.54	0.15
2:40 pm	0.80	-1.09	-10.74	-4.41
3:25 pm	50.79	-9.81	9.94	-13.27
4:20 pm	52.95	3.84	23.23	-0.39
5:00 pm	97.93	0.06	28.09	-5.24
Mean Difference	49.65	-0.44	6.45	-2.97
Standard Deviation	31.03	8.12	14.48	5.68
t calculated	4.525	-0.154	1.260	-1.480
Conclusion	reject H_o	cannot reject H_o	cannot reject H_o	cannot reject H_o
Probability to Accept H_o $(1-\beta)$	———	0.97	0.85	0.80

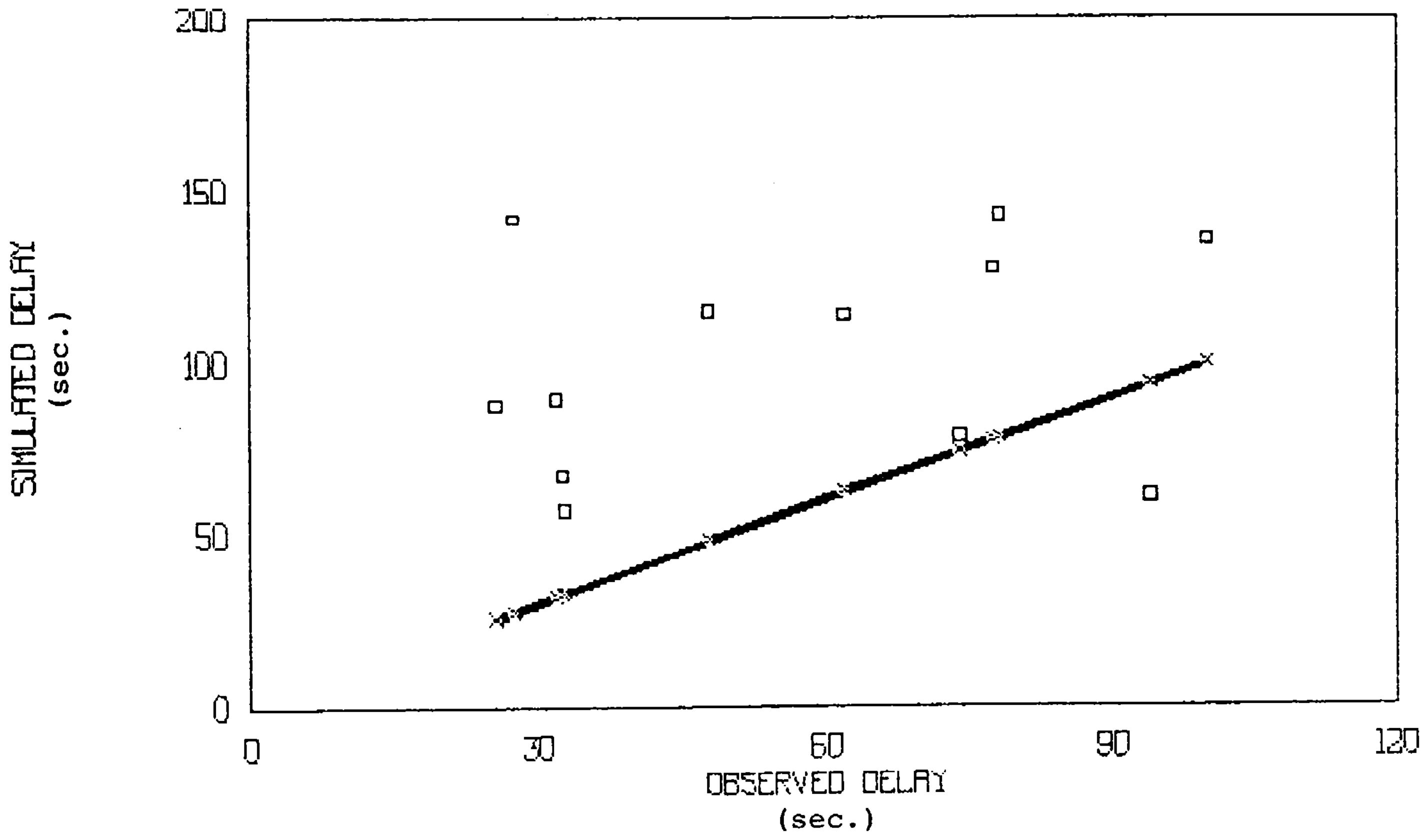
Note : n = 8, $t_{(0.025,7)} = 2.365$

- Average Stopped Delay Results For Stonex's Scenario (Exclusive/Permissive Left Turns)

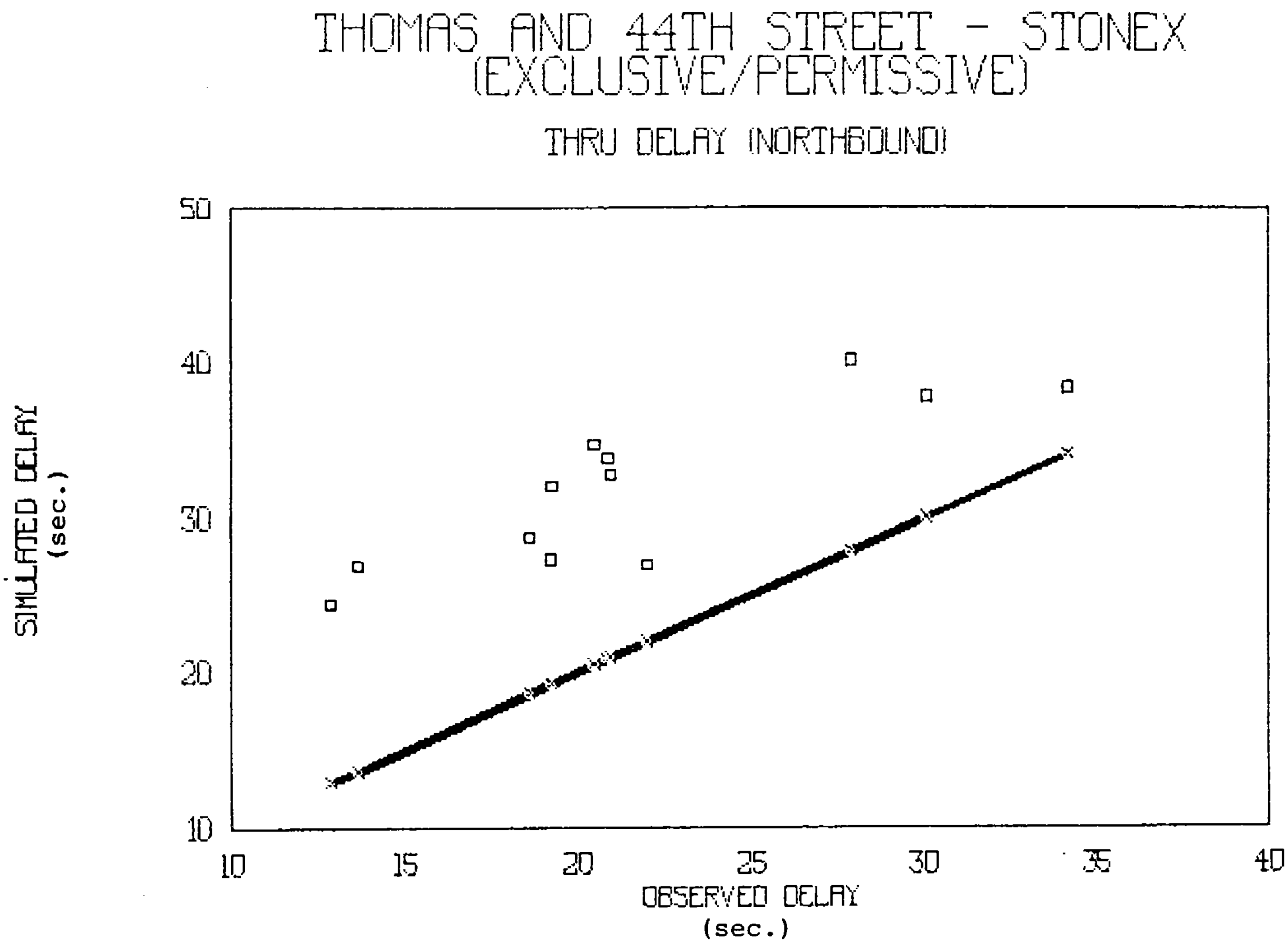
Time of Day	Average Stopped Delay (sec)							
	Northbound Approach				Southbound Approach			
	Left Turn		Through		Left Turn		Through	
	Sim.	Obs.	Sim.	Obs.	Sim.	Obs.	Sim.	Obs.
8:35 am	89.4	31.9	28.7	18.6	54.9	27.1	28.0	33.6
8:45 am	57.0	32.9	27.0	22.0	54.1	26.7	27.6	30.0
8:55 am	88.0	25.6	27.0	13.7	24.8	21.8	26.5	18.7
9:15 am	67.1	32.6	24.5	12.8	43.5	28.2	23.3	19.1
11:00 am	141.9	27.5	32.1	19.3	99.2	33.8	28.3	25.4
11:10 am	127.0	77.6	27.3	19.2	48.3	34.2	26.6	20.9
12:10 pm	135.7	99.9	34.8	20.5	117.6	38.8	30.6	28.7
1:15 pm	142.9	78.3	33.9	20.9	108.2	36.6	28.2	30.4
3:20 pm	114.0	62.1	32.8	20.9	77.0	35.2	29.1	22.8
3:45 pm	114.7	47.9	37.8	30.1	56.7	59.0	31.6	29.4
4:05 pm	60.8	94.0	40.2	27.9	95.4	51.2	34.8	32.2
4:45 pm	78.2	74.1	38.4	34.2	69.6	44.6	30.3	30.6
Mean Del.	101.4	57.0	32.0	21.7	70.8	36.4	28.7	26.8
Std. Dev.	33.33	28.44	5.41	6.54	30.10	11.26	3.01	5.47

THOMAS AND 44TH STREET - STONEX
(EXCLUSIVE/PERMISSIVE)

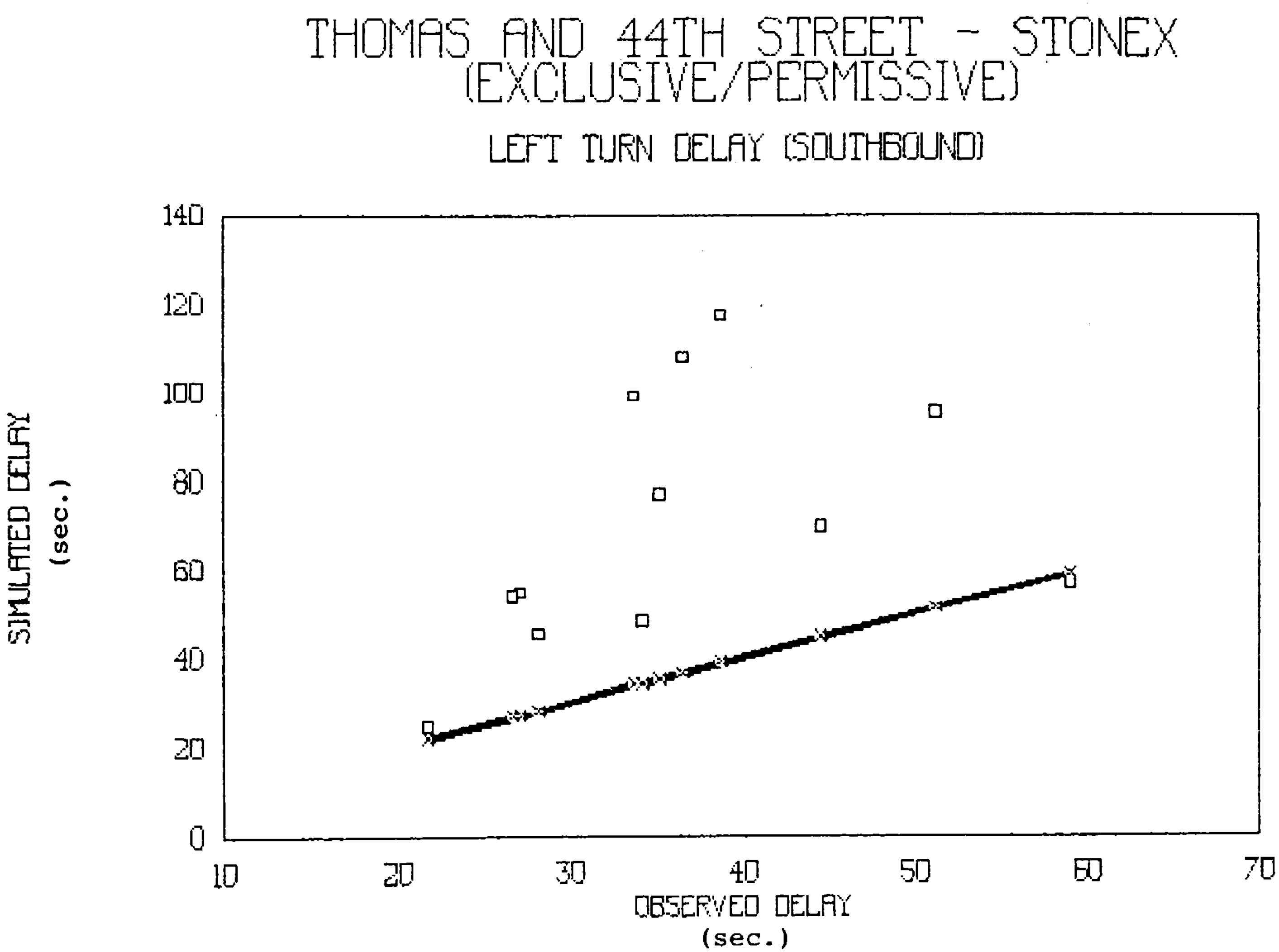
LEFT TURN DELAY (NORTHBOUND)



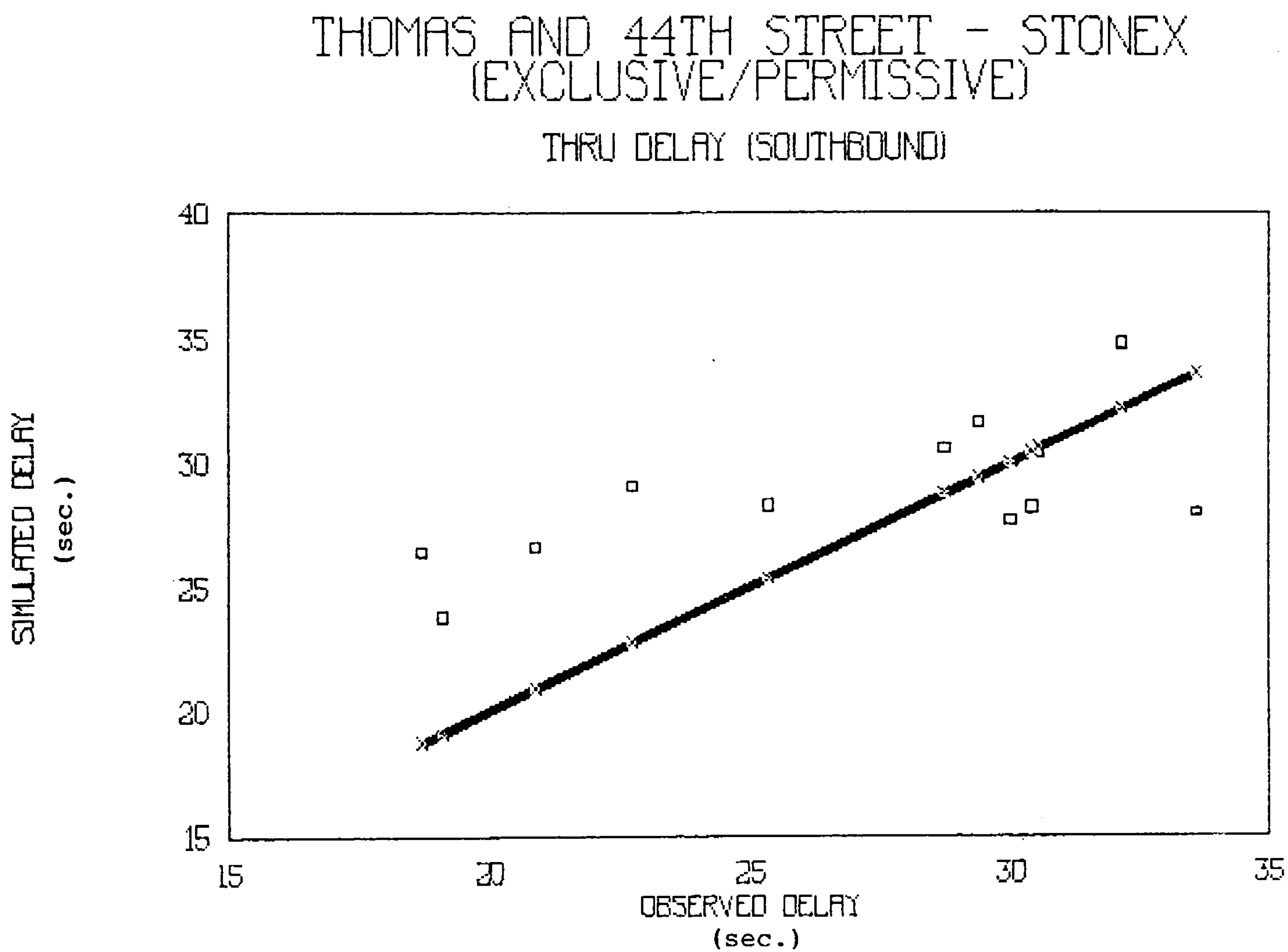
- Stonex's Scenario Northbound Left Turn Results



- Stonex's Scenario Northbound Through Results



- Stonex's Scenario Southbound Left Turn Results



- Stonex's Scenario Southbound Through Results

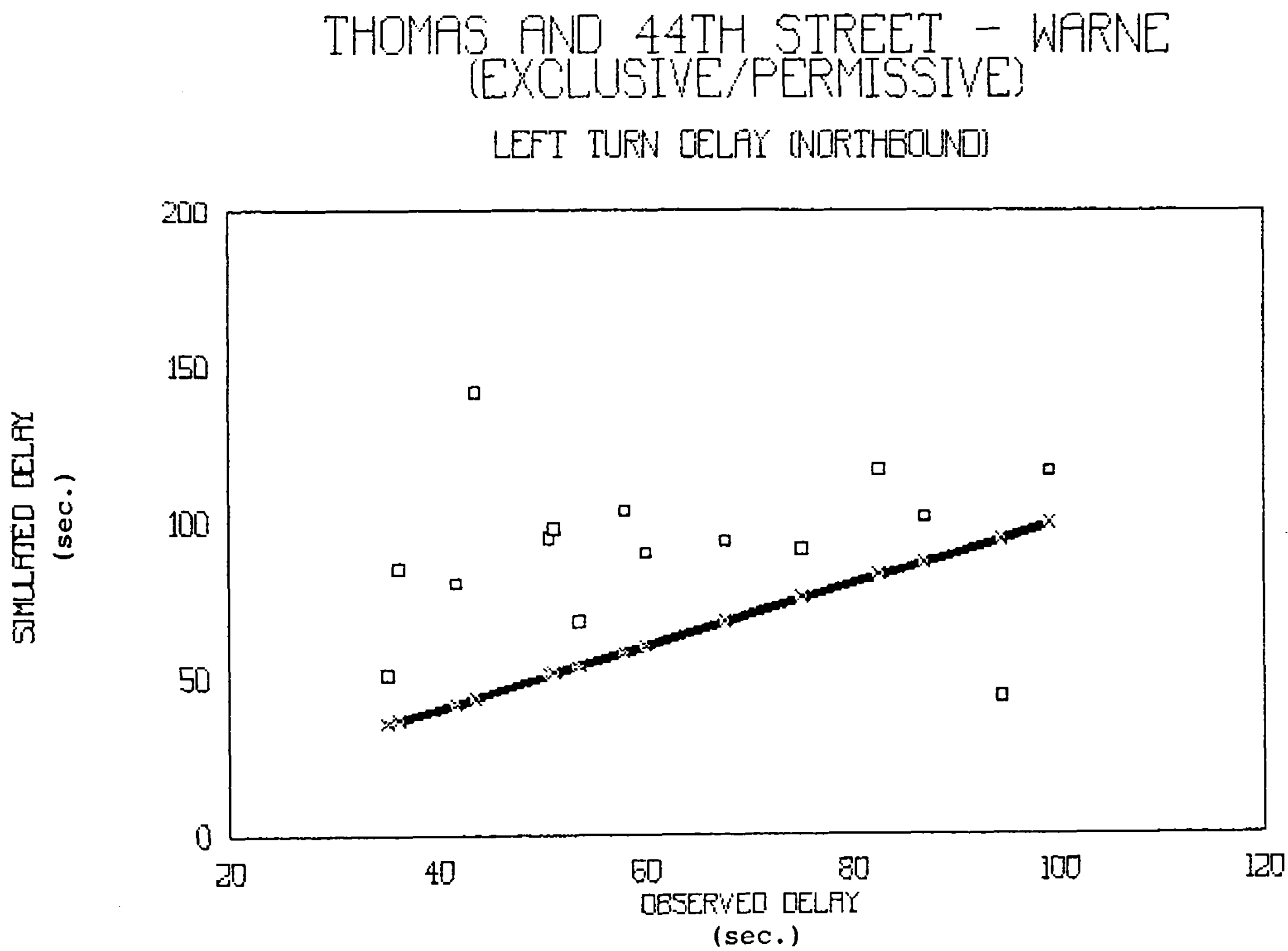
- Paired Data t-Test Results For Stonex's Scenario (Exclusive/Permissive Left Turns)

Time of Day	Difference Between Simulated and Observed Delay Results (sec)			
	Northbound Approach		Southbound Approach	
	Left Turn	Through	Left Turn	Through
8:35 am	57.43	10.06	27.80	-5.63
8:45 am	24.10	4.99	27.41	-2.39
8:55 am	62.41	13.34	3.04	7.77
9:15 am	34.46	11.63	15.34	4.23
11:00 am	114.44	12.82	65.44	2.92
11:10 am	49.35	8.04	14.04	5.74
12:10 pm	35.85	14.27	78.87	1.85
1:15 pm	64.60	13.00	71.60	-2.23
3:20 pm	51.97	11.88	41.84	6.30
3:45 pm	66.87	7.75	-2.26	2.20
4:05 pm	-33.28	12.33	44.15	2.59
4:45 pm	4.05	4.28	25.07	-0.23
Mean Difference	44.35	10.36	34.36	1.93
Standard Deviation	38.10	3.49	27.74	4.13
t calculated	4.032	10.280	4.291	1.615
Conclusion	reject H_o	reject H_o	reject H_o	cannot reject H_o
Probability to Accept H_o $(1-\beta)$	——	——	——	0.71

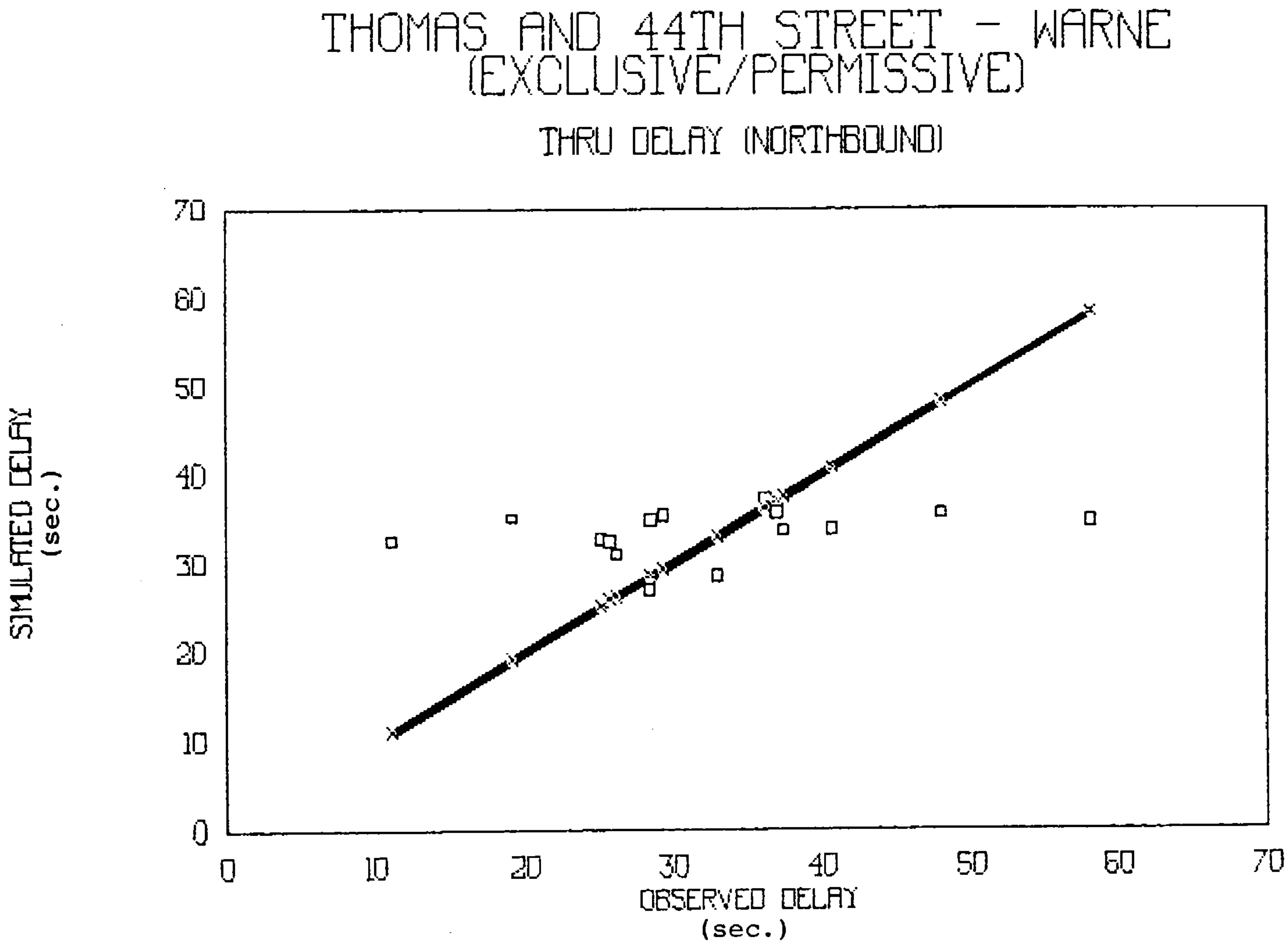
Note : n = 12, $t_{(0.025,11)} = 2.201$

- Average Stopped Delay Results For Warne's Scenario (Exclusive/Permissive Left Turns)

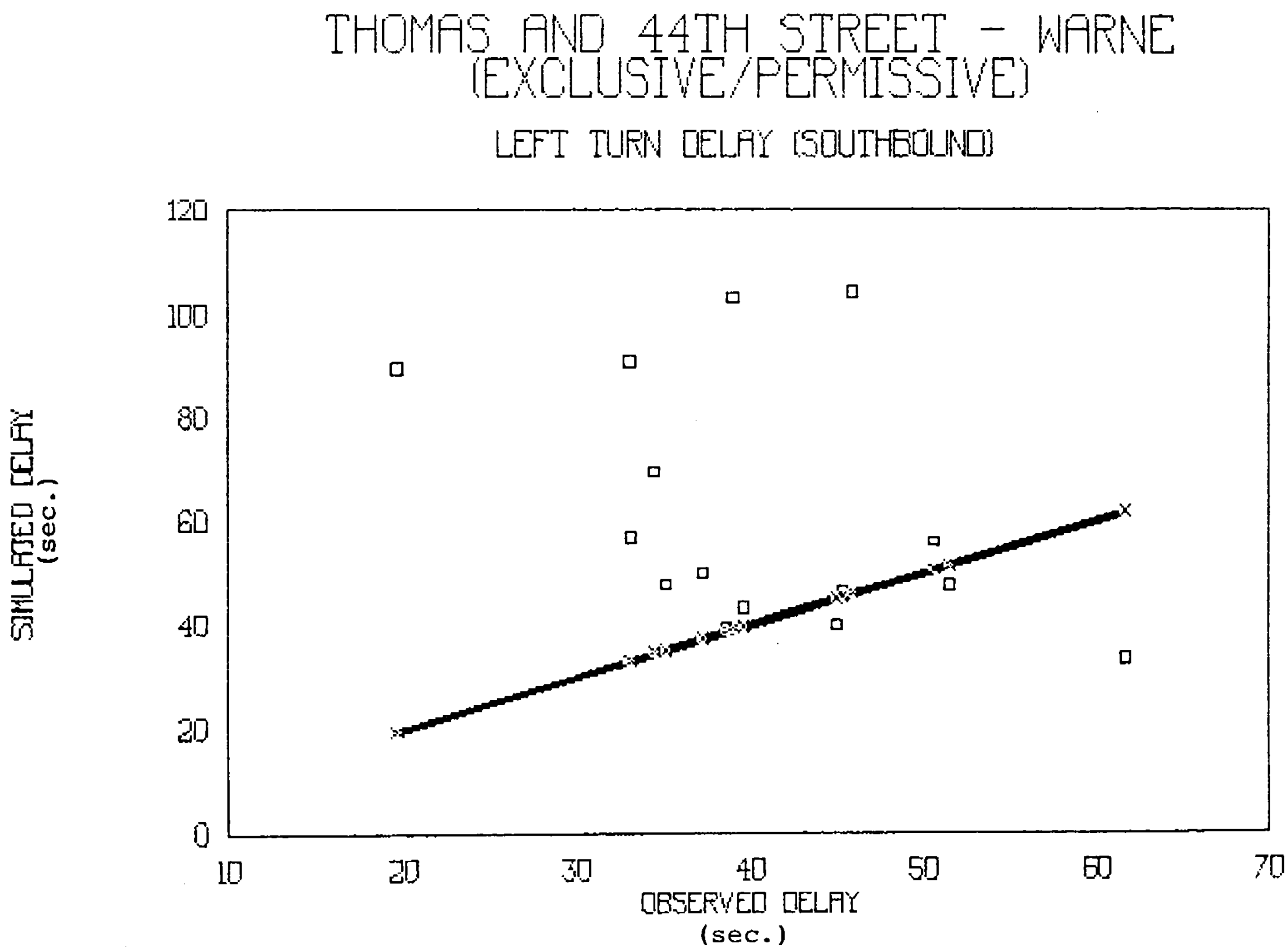
Time of Day	Average Stopped Delay (sec)							
	Northbound Approach				Southbound Approach			
	Left Turn		Through		Left Turn		Through	
	Sim.	Obs.	Sim.	Obs.	Sim.	Obs.	Sim.	Obs.
8:30 am	85.5	36.3	35.0	19.2	91.1	33.1	32.2	21.7
8:40 am	142.0	43.7	32.6	11.1	46.5	45.4	31.1	23.4
9:00 am	51.0	35.2	32.7	25.2	89.8	19.7	33.5	23.6
10:20 am	95.0	50.8	27.0	28.5	33.2	61.7	25.3	33.0
11:00 am	103.8	58.0	35.3	48.0	56.0	50.6	30.3	38.6
11:30 am	116.1	82.5	35.4	29.4	50.1	37.3	29.0	24.1
11:40 am	101.3	86.9	37.2	36.2	47.8	35.2	28.9	33.2
12:10 pm	115.8	99.0	33.9	40.8	47.3	51.5	27.9	39.9
12:20 pm	43.0	94.4	35.7	37.0	69.9	34.5	26.1	44.9
1:25 pm	90.8	75.1	33.6	37.4	43.1	39.6	27.5	35.7
1:55 pm	98.0	51.2	31.1	26.3	39.8	45.0	28.1	34.6
2:40 pm	90.3	60.1	32.5	25.8	56.7	33.1	30.3	33.5
4:15 pm	68.1	53.6	28.5	33.0	38.8	38.6	26.3	27.5
5:15 pm	80.4	41.8	34.6	58.1	104.3	45.9	34.1	39.3
5:25 pm	94.0	67.7	34.9	28.5	103.4	39.0	34.9	26.9
Mean Del.	91.7	62.4	33.3	32.3	61.2	40.7	29.7	32.0
Std. Dev.	25.89	21.63	2.84	11.85	25.12	10.23	3.10	7.37



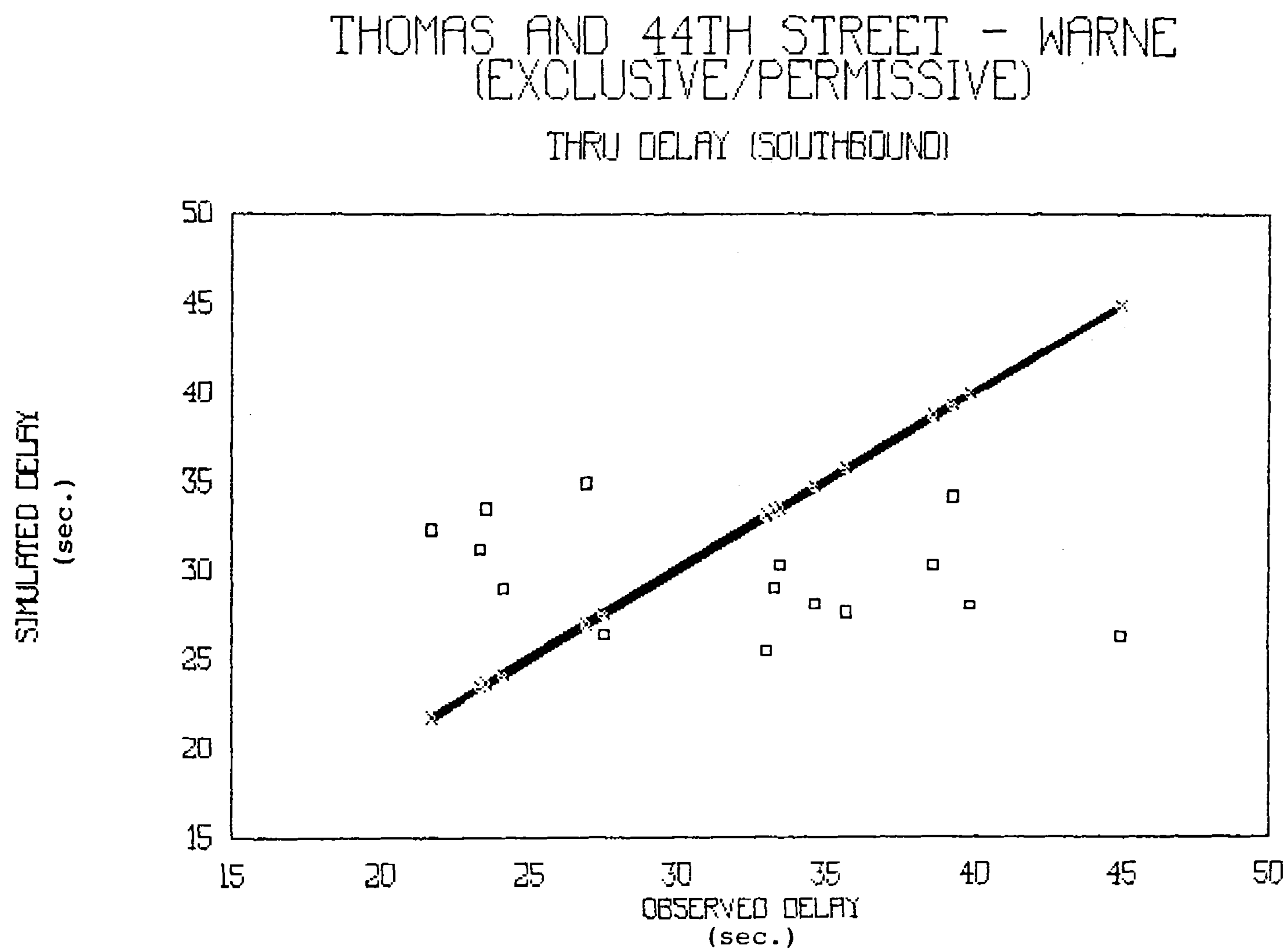
- Warne's Scenario Northbound Left Turn Results



- Warne's Scenario Northbound Through Results



- Warne's Scenario Southbound Left Turn Results



- Warne's Scenario Southbound Through Results

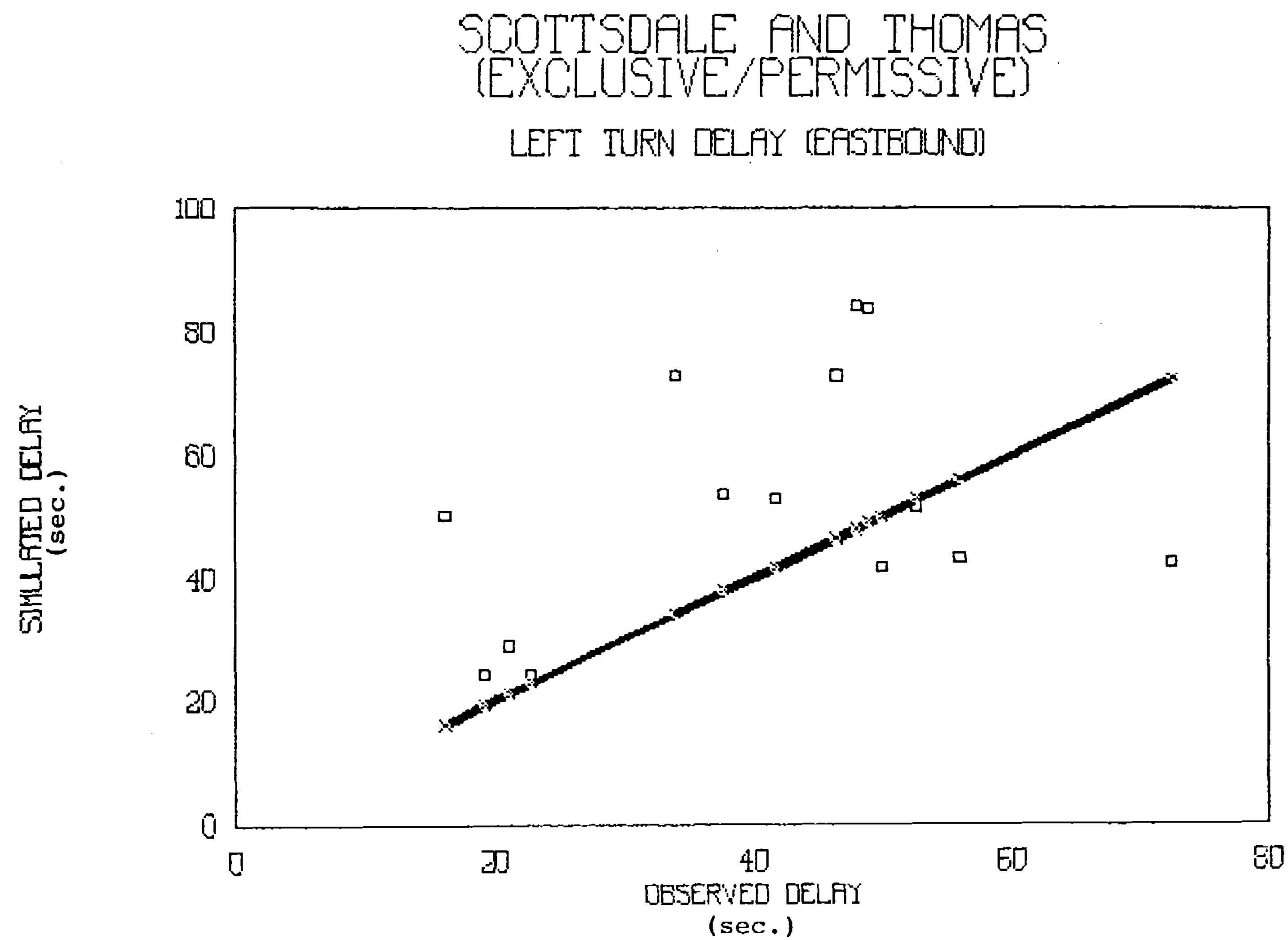
- Paired Data t-Test Results For Warne's Scenario (Exclusive/Permissive Left Turns)

Time of Day	Difference Between Simulated and Observed Delay Results (sec)			
	Northbound Approach		Southbound Approach	
	Left Turn	Through	Left Turn	Through
8:30 am	49.17	15.86	57.98	10.50
8:40 am	98.36	21.51	1.19	7.72
9:00 am	15.83	7.53	70.15	9.89
10:20 am	44.16	-1.50	-28.43	-7.65
11:00 am	45.73	-12.68	5.39	-8.34
11:30 am	33.59	6.04	12.84	4.84
11:40 am	14.39	1.00	12.68	-4.30
12:10 pm	16.82	-6.90	-4.15	-11.91
12:20 pm	-51.38	-1.32	35.36	-18.81
1:25 pm	15.71	-3.84	3.52	-8.16
1:55 pm	46.81	4.84	-5.15	-6.56
2:40 pm	30.20	6.72	23.58	-3.19
4:15 pm	14.44	-4.44	0.21	-1.28
5:15 pm	38.68	-23.48	58.33	-5.15
5:25 pm	26.29	6.34	64.37	7.97
Mean Difference	29.25	1.05	20.52	-2.30
Standard Deviation	32.20	11.40	30.98	9.03
t calculated	3.518	0.355	2.566	-0.985
Conclusion	reject H_o	cannot reject H_o	reject H_o	cannot reject H_o
Probability to Accept H_o $(1-\beta)$	———	0.95	———	0.87

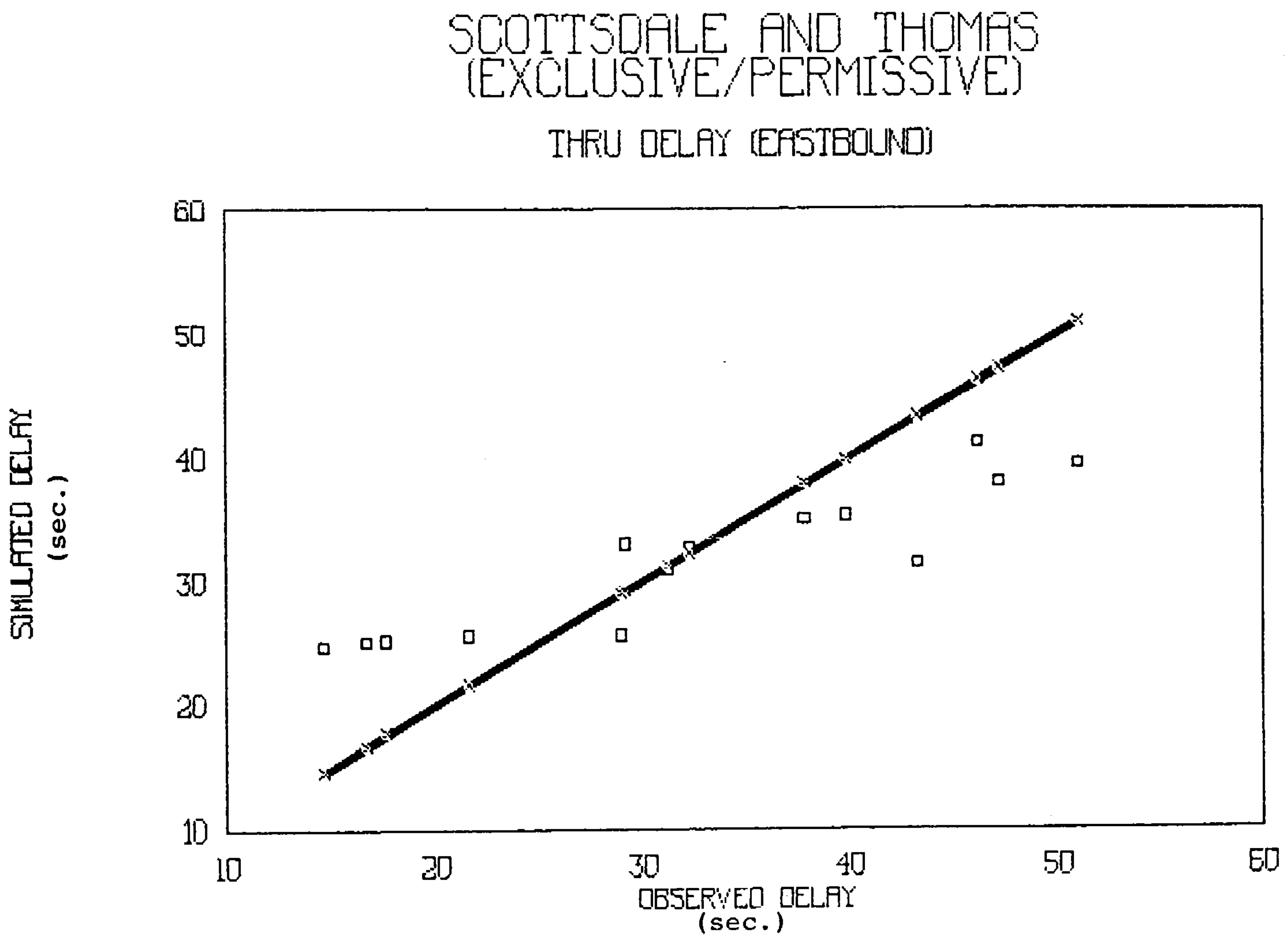
Note : n = 15, $t_{(0.025,14)} = 2.145$

- Average Stopped Delay Results For Scottsdale and Thomas (Exclusive/Permissive Left Turns)

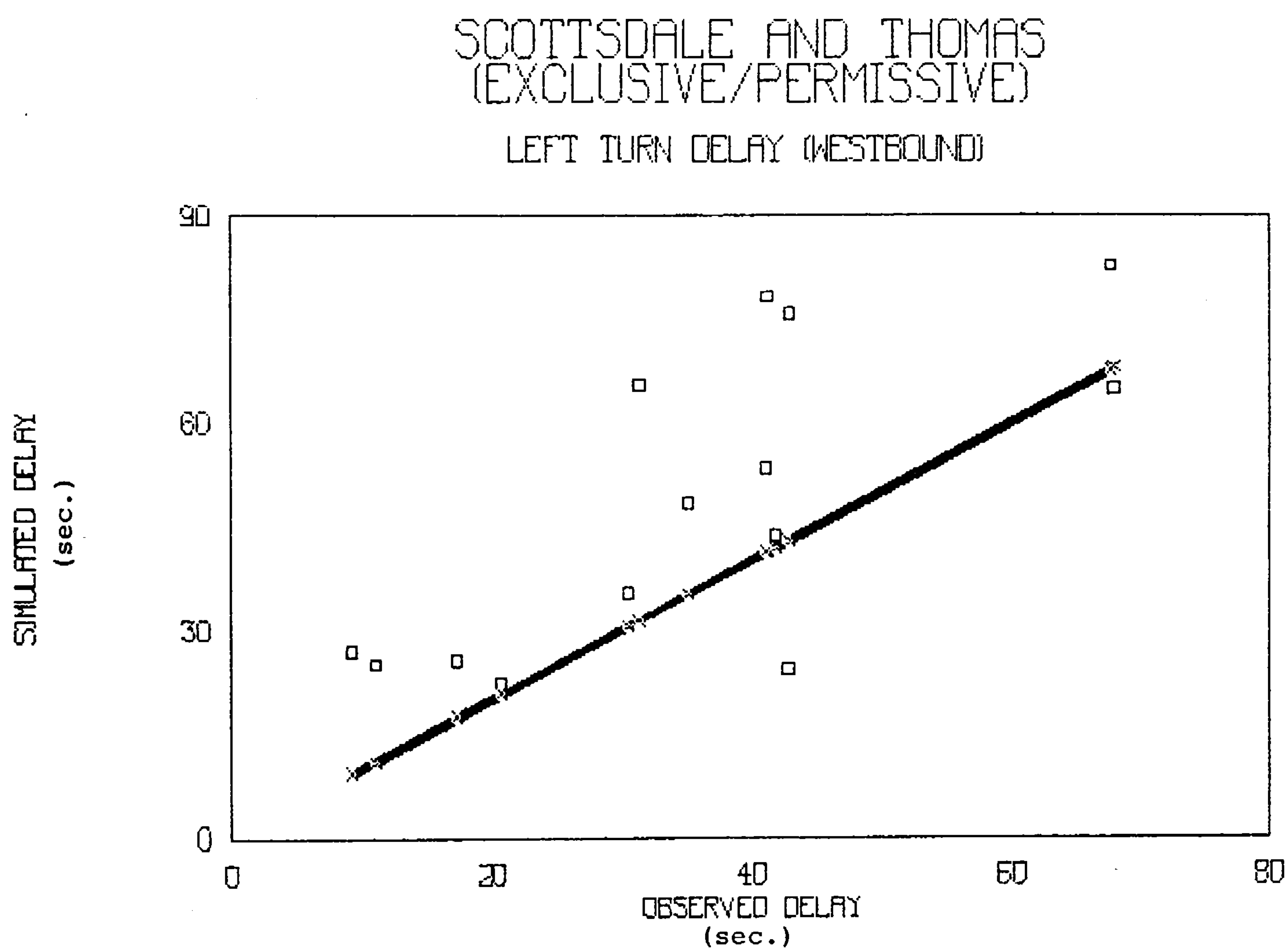
Time of Day	Average Stopped Delay (sec)							
	Eastbound Approach				Westbound Approach			
	Left Turn		Through		Left Turn		Through	
	Sim.	Obs.	Sim.	Obs.	Sim.	Obs.	Sim.	Obs.
8:10 am	23.9	22.8	25.1	17.7	27.0	9.3	22.9	21.3
8:20 am	23.9	19.2	24.7	14.6	25.4	17.4	24.3	14.2
8:30 am	50.3	16.2	25.1	16.7	22.0	20.7	25.8	15.0
8:40 am	28.6	21.2	25.6	21.6	24.9	11.0	24.9	13.9
11:55 am	52.8	41.7	32.9	29.2	65.6	31.4	32.6	38.2
12:15 pm	42.5	72.4	31.0	31.2	35.4	30.5	28.1	42.1
1:35 pm	41.5	50.0	25.6	29.0	24.3	42.9	25.8	37.6
2:05 pm	73.1	34.0	32.7	32.3	65.0	67.9	34.3	34.2
3:05 pm	72.9	46.5	35.1	39.8	82.9	67.7	39.5	30.2
3:35 pm	51.4	52.7	35.0	37.8	78.6	41.3	35.9	38.1
3:45 pm	53.7	37.8	31.5	43.3	53.6	41.2	39.5	30.4
4:10 pm	82.7	48.0	37.6	47.2	43.9	41.9	41.7	35.5
4:30 pm	83.7	48.9	39.3	51.0	48.5	35.2	38.5	34.3
4:50 pm	43.3	56.0	41.1	46.2	76.0	43.0	37.3	34.1
Mean Del.	51.7	40.5	31.6	32.7	48.1	35.8	32.2	29.9
Std. Dev.	20.83	16.89	5.90	12.46	23.15	18.60	6.95	10.10



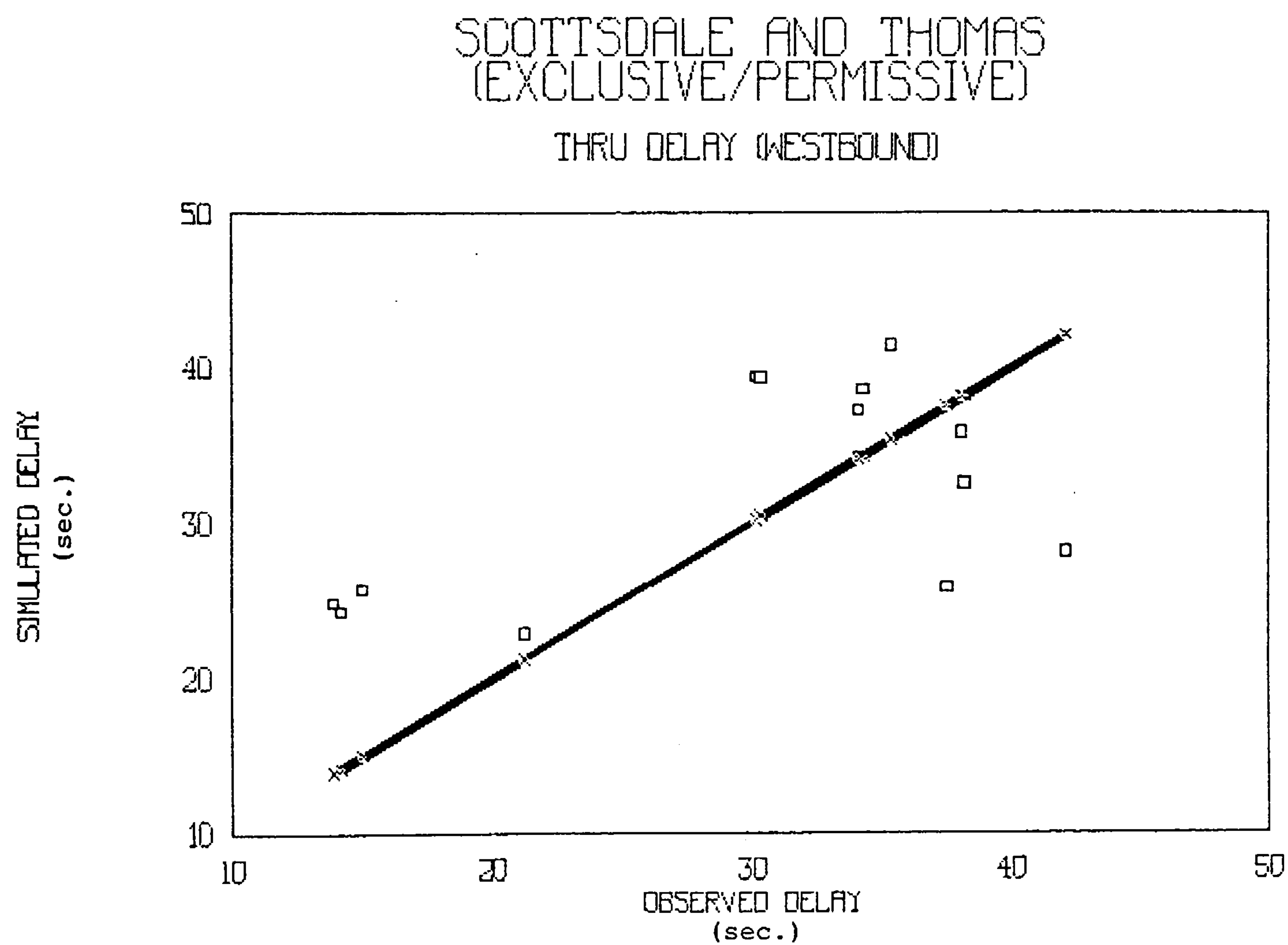
- Scottsdale and Thomas Eastbound Left Turn Results



- Scottsdale and Thomas Eastbound Through Results



- Scottsdale and Thomas Westbound Left Turn Results



- Scottsdale and Thomas Westbound Through Results

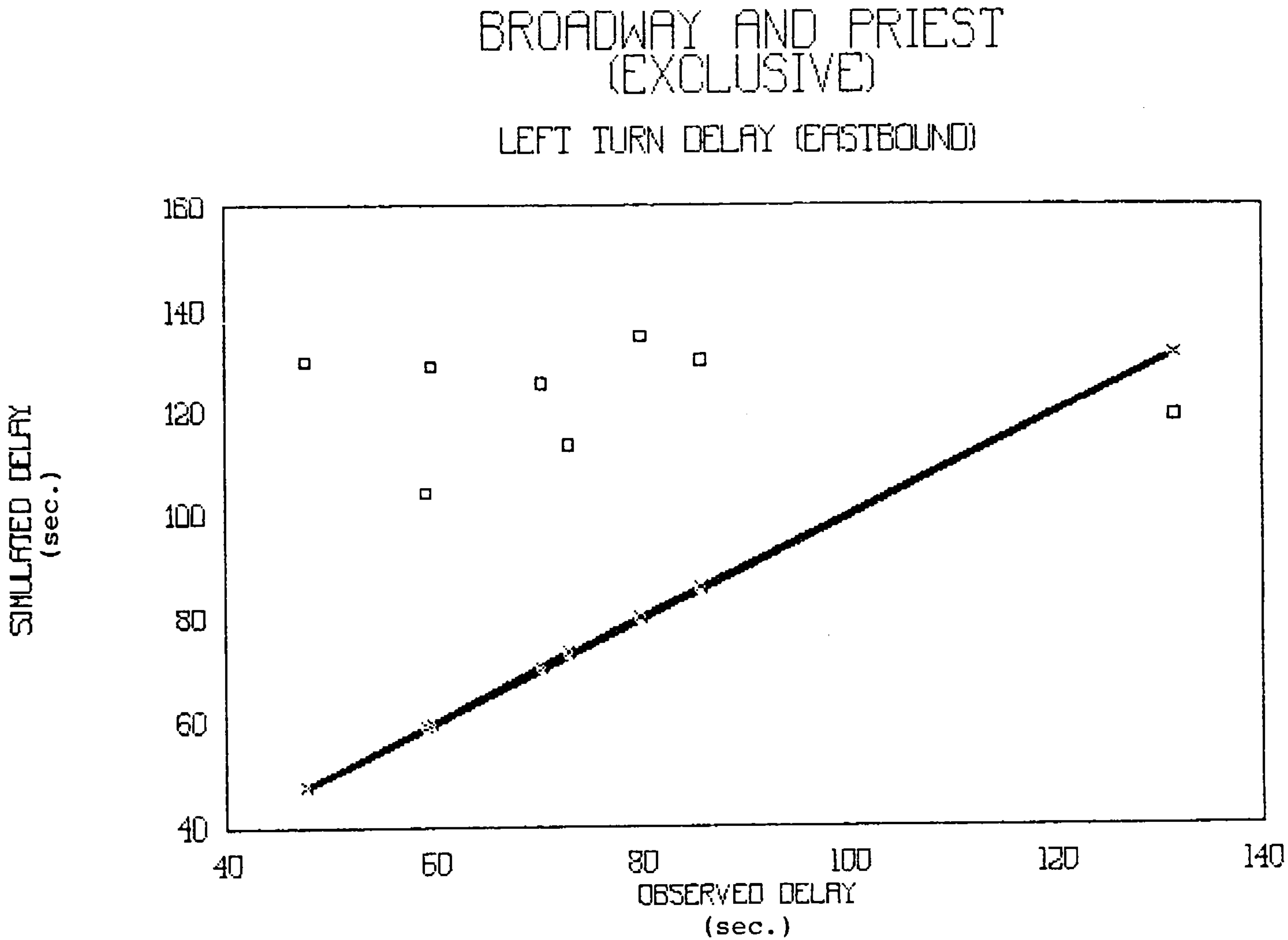
- Paired Data t-Test Results For Scottsdale and Thomas (Exclusive/Permissive Left Turns)

Time of Day	Difference Between Simulated and Observed Delay Results (sec)			
	Eastbound Approach		Westbound Approach	
	Left Turn	Through	Left Turn	Through
8:10 am	1.14	7.39	17.67	1.63
8:20 am	4.71	10.05	8.03	10.15
8:30 am	34.15	8.40	1.31	10.80
8:40 am	7.40	3.95	13.84	11.02
11:55 am	11.11	3.69	34.27	-5.60
12:15 pm	-29.94	-0.23	4.89	-14.02
1:35 pm	-8.53	-3.45	-18.54	-11.76
2:05 pm	39.11	0.47	-2.92	0.18
3:05 pm	26.44	-4.67	15.21	9.34
3:35 pm	-1.24	-2.84	37.32	-2.21
3:45 pm	15.97	-11.84	12.40	9.10
4:10 pm	34.77	-9.57	2.03	6.26
4:30 pm	34.75	-11.71	13.30	4.21
4:50 pm	-12.73	-5.02	33.04	3.16
Mean Difference	11.22	-1.10	12.27	2.30
Standard Deviation	21.61	7.48	15.93	8.53
t calculated	1.943	-0.550	2.884	1.011
Conclusion	cannot reject H_o	cannot reject H_o	reject H_o	cannot reject H_o
Probability to Accept H_o $(1-\beta)$	0.51	0.93	——	0.91

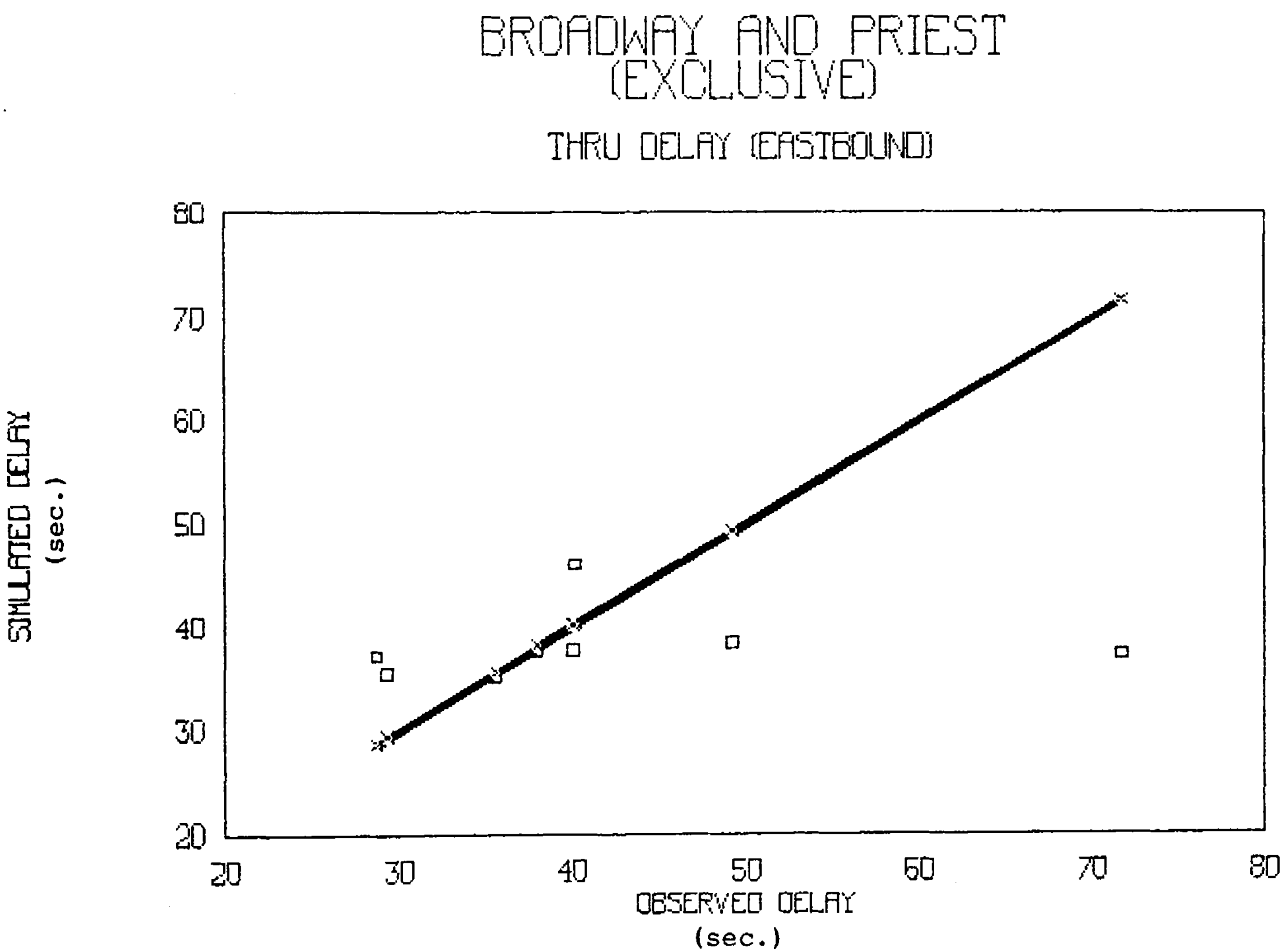
Note : $n = 14$, $t_{(0.025,13)} = 2.160$

- Average Stopped Delay Results For Broadway and Priest (Exclusive Left Turns)

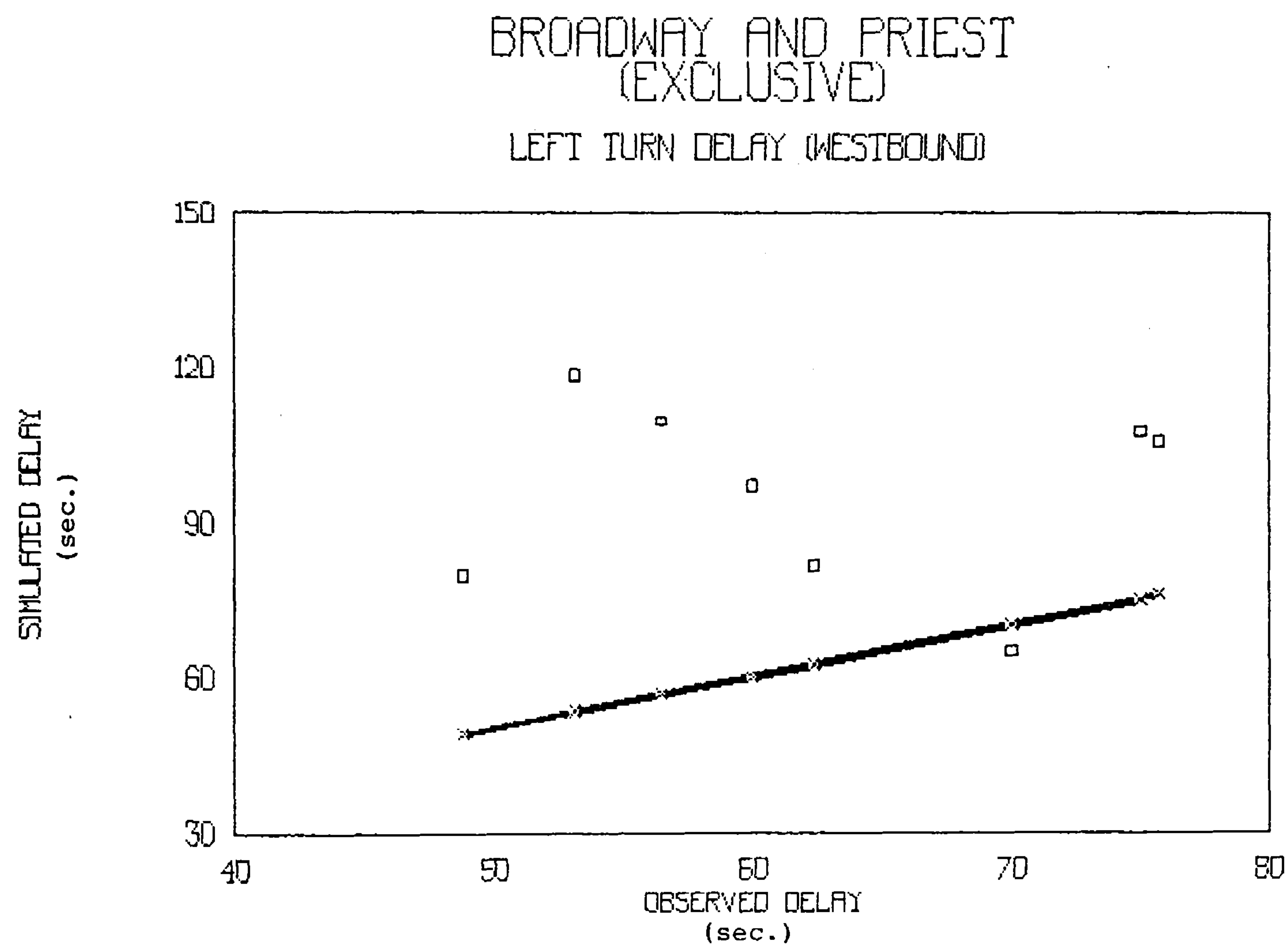
Time of Day	Average Stopped Delay (sec)							
	Eastbound Approach				Westbound Approach			
	Left Turn		Through		Left Turn		Through	
	Sim.	Obs.	Sim.	Obs.	Sim.	Obs.	Sim.	Obs.
9:40 am	113.3	73.0	35.0	35.6	64.9	70.0	38.6	43.6
10:55 am	104.1	59.2	35.5	29.3	79.5	48.8	40.2	47.5
11:40 am	130.0	47.6	46.2	40.2	107.9	75.0	50.4	35.7
2:10 pm	129.1	59.7	37.2	28.7	97.0	60.0	42.5	49.1
2:30 pm	134.8	80.0	37.7	40.1	81.6	62.4	36.7	45.1
2:40 pm	118.7	131.4	37.8	38.0	105.9	75.7	41.4	42.6
3:45 pm	130.3	85.8	37.2	71.7	118.6	53.1	43.1	56.2
4:25 pm	125.7	70.4	38.3	49.3	109.8	56.5	41.1	54.2
Mean Del.	123.3	75.9	38.1	41.6	95.6	62.7	41.7	46.7
Std. Dev.	11.09	27.33	3.68	14.76	19.71	10.73	4.34	7.01



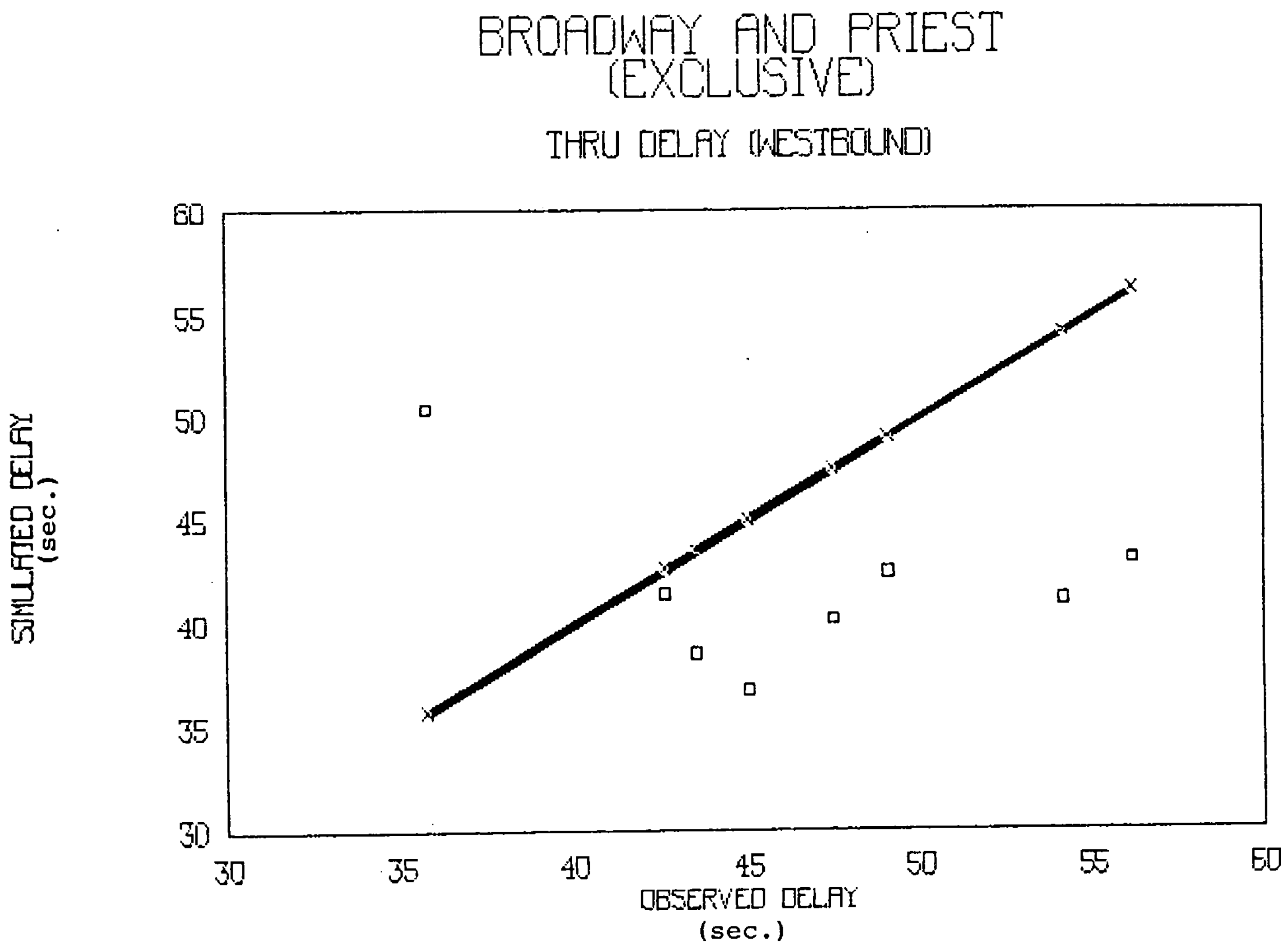
- Broadway and Priest Eastbound Left Turn Results



- Broadway and Priest Eastbound Through Results



- Broadway and Priest Westbound Left Turn Results



- Broadway and Priest Westbound Through Results

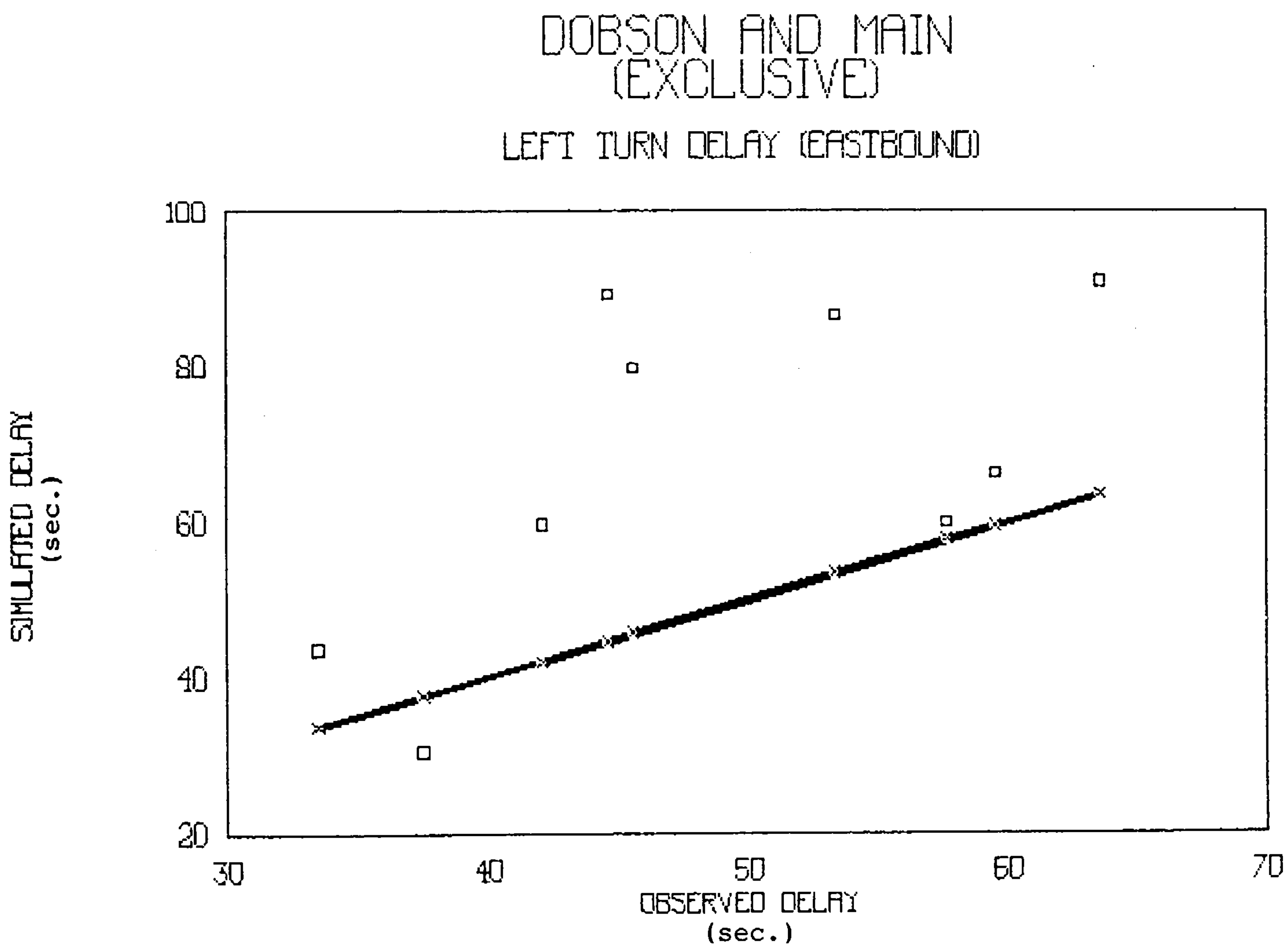
- Paired Data t-Test Results For Broadway and Priest (Exclusive Left Turns)

Time of Day	Difference Between Simulated and Observed Delay Results (sec)			
	Eastbound Approach		Westbound Approach	
	Left Turn	Through	Left Turn	Through
9:40 am	40.34	-0.60	-5.09	-4.99
10:55 am	44.93	6.17	30.70	-7.34
11:40 am	82.35	5.98	32.86	14.65
2:10 pm	69.43	8.50	37.02	-6.63
2:30 pm	54.77	-2.35	19.28	-8.32
2:40 pm	-12.69	-0.25	30.15	-1.18
3:45 pm	44.46	-34.51	65.45	-13.09
4:25 pm	55.28	-10.97	53.30	-13.06
Mean Difference	47.36	-3.50	32.96	-5.00
Standard Deviation	29.96	14.93	22.62	9.48
t calculated	4.470	-0.664	4.121	-1.490
Conclusion	reject H_o	cannot reject H_o	reject H_o	cannot reject H_o
Probability to Accept H_o $(1-\beta)$	———	0.93	———	0.79

Note : $n = 8$, $t_{(0.025,7)} = 2.365$

- Average Stopped Delay Results For Dobson and Main (Exclusive Left Turns)

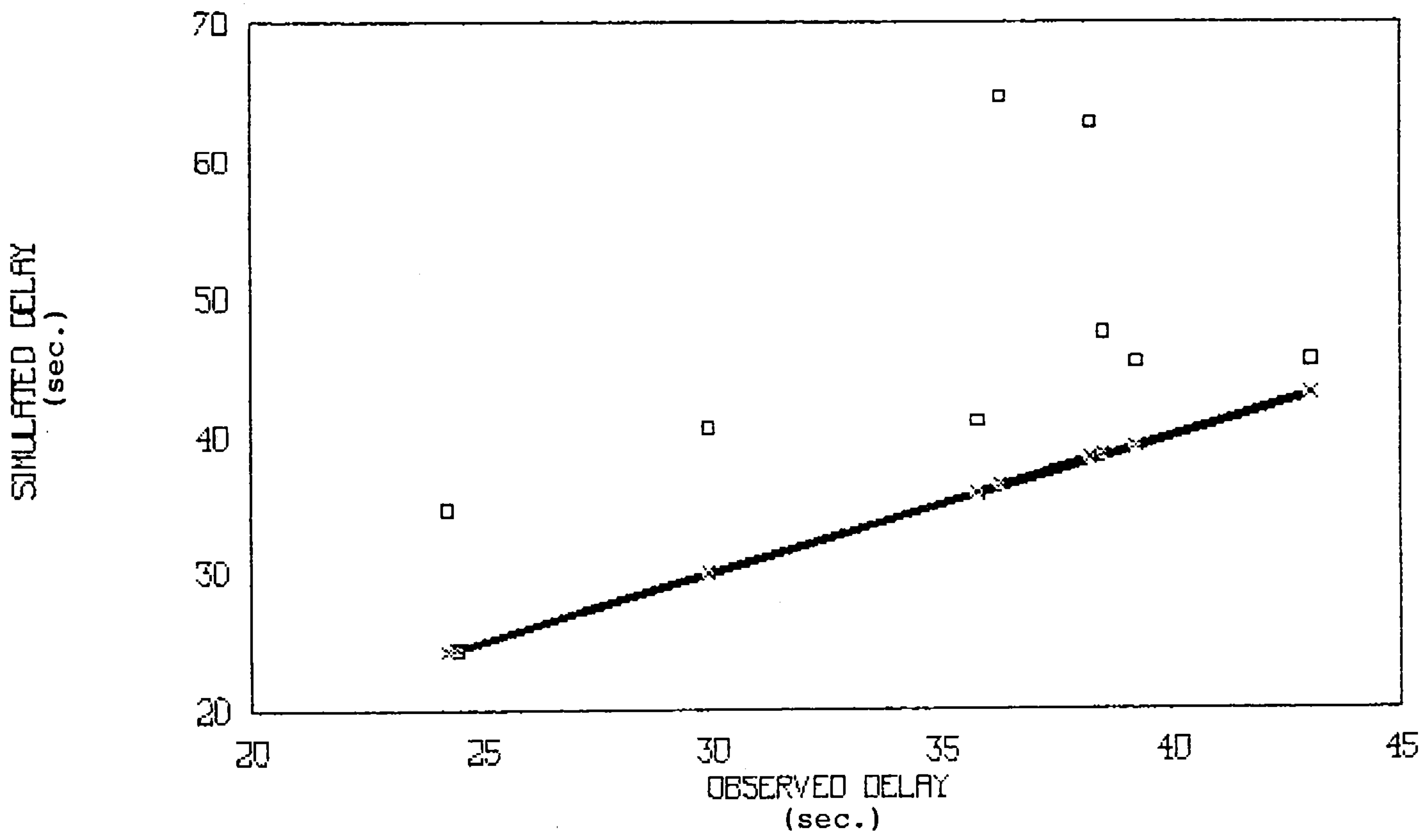
Time of Day	Average Stopped Delay (sec)							
	Eastbound Approach				Westbound Approach			
	Left Turn		Through		Left Turn		Through	
	Sim.	Obs.	Sim.	Obs.	Sim.	Obs.	Sim.	Obs.
8:30 am	30.5	37.5	24.4	24.5	29.6	27.9	20.2	22.9
9:10 am	43.7	33.5	34.6	24.2	43.5	29.8	30.1	26.1
10:30 am	59.8	57.6	40.5	29.9	59.8	47.7	38.0	31.2
12:50 pm	89.3	44.6	45.2	39.2	84.4	69.8	37.1	35.1
1:00 pm	91.0	63.5	45.3	43.0	80.8	68.7	39.5	35.5
2:10 pm	59.6	42.1	41.1	35.8	62.3	40.5	37.2	36.7
3:30 pm	66.2	59.5	47.4	38.5	76.6	54.1	38.6	28.0
3:50 pm	86.8	53.3	62.9	38.2	76.4	53.0	40.0	36.5
4:10 pm	80.0	45.6	64.6	36.3	67.8	38.8	38.3	32.6
Mean Del.	67.4	48.6	45.1	34.4	64.6	47.8	35.5	31.6
Std. Dev.	22.54	11.04	13.43	7.08	19.29	16.08	6.80	5.28



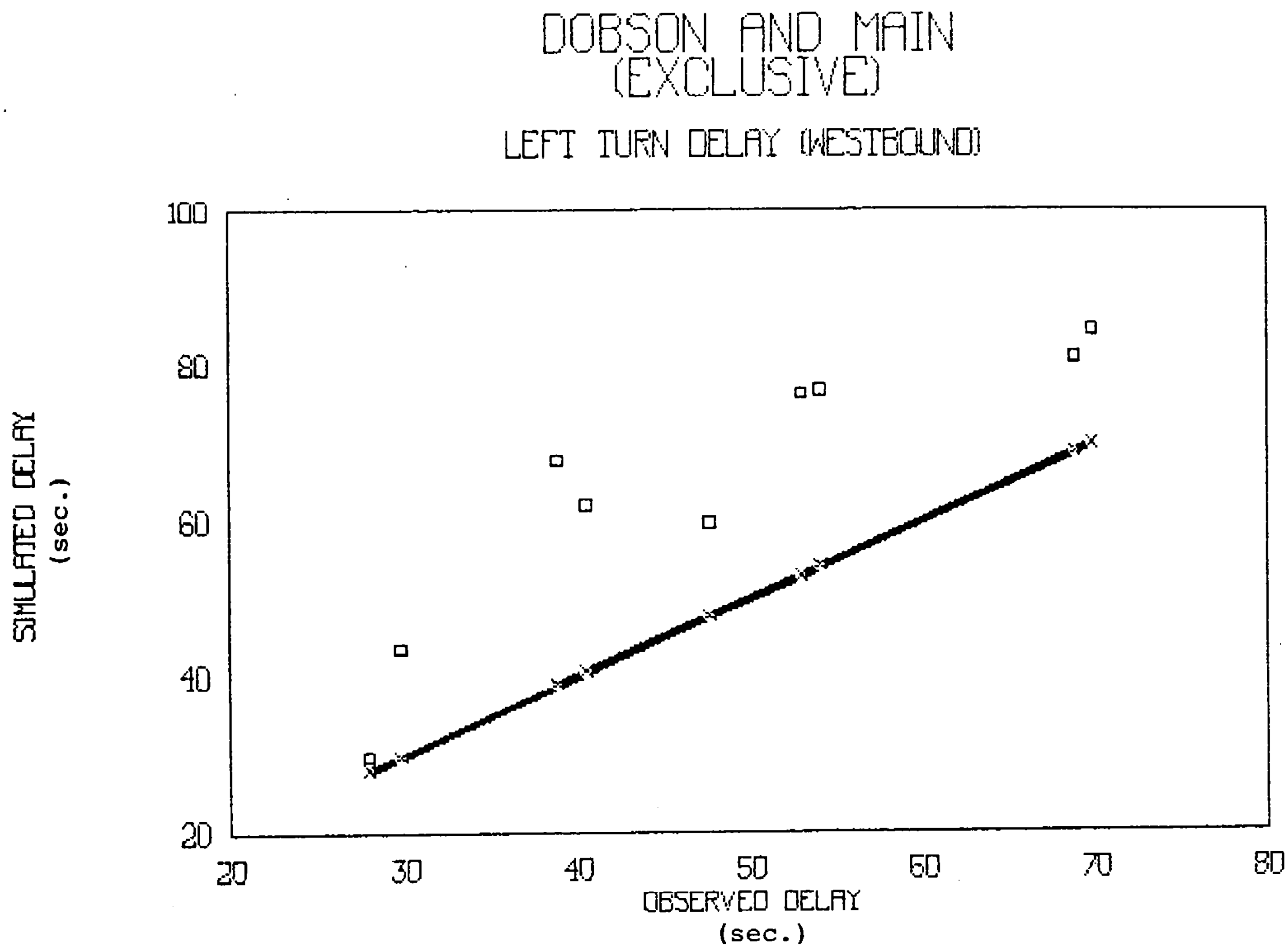
- Dobson and Main Eastbound Left Turn Results

DOBSON AND MAIN
(EXCLUSIVE)

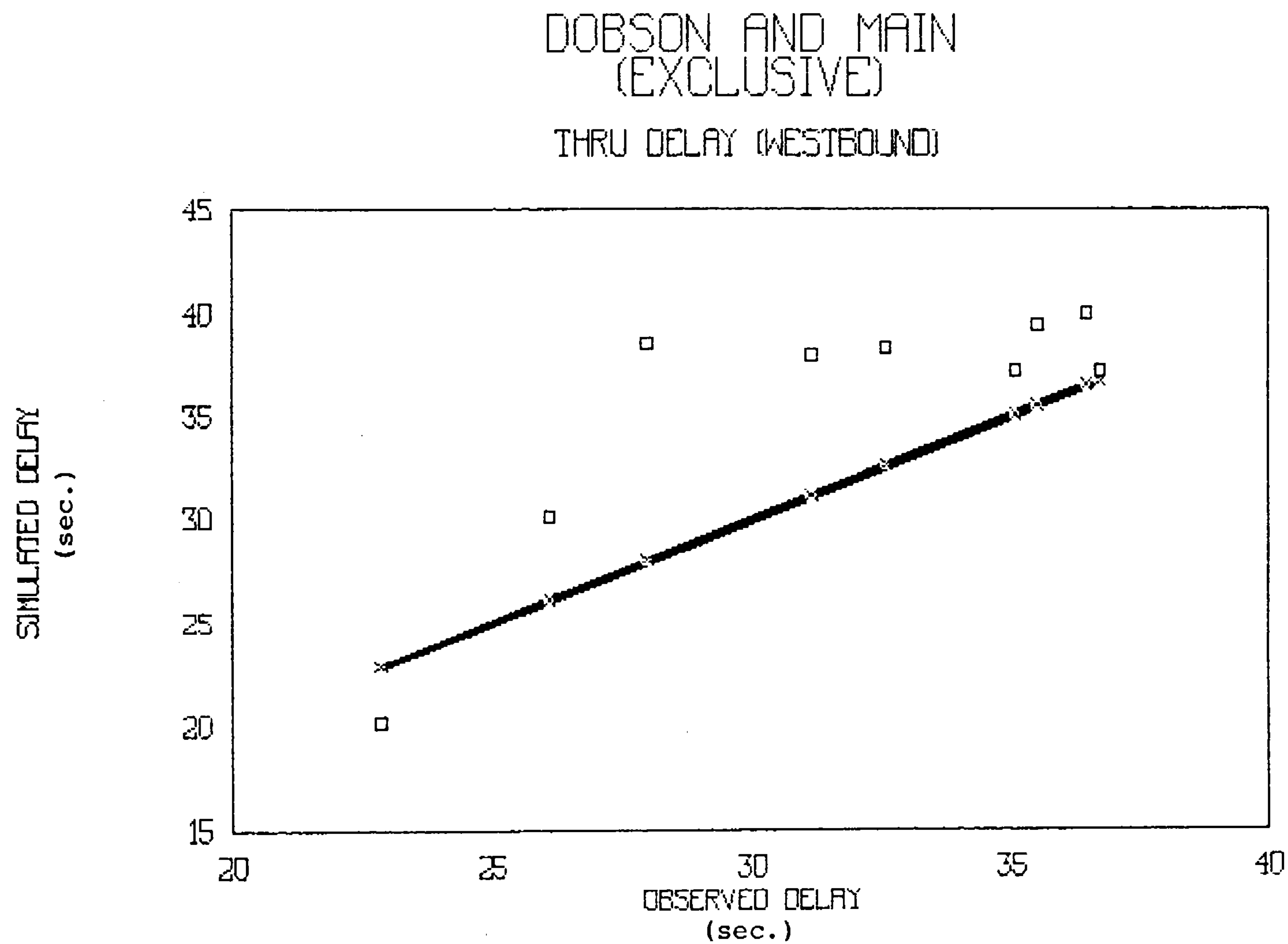
THRU DELAY (EASTBOUND)



- Dobson and Main Eastbound Through Results



- Dobson and Main Westbound Left Turn Results



- Dobson and Main Westbound Through Results

- Paired Data t-Test Results For Dobson and Main (Exclusive Left Turns)

Time of Day	Difference Between Simulated and Observed Delay Results (sec)			
	Eastbound Approach		Westbound Approach	
	Left Turn	Through	Left Turn	Through
8:30 am	-6.96	-0.11	1.65	-2.69
9:10 am	10.23	10.39	13.72	4.02
10:30 am	2.12	10.53	12.10	6.82
12:50 pm	44.74	6.00	14.63	2.04
1:00 pm	27.42	2.26	12.07	3.94
2:10 pm	17.52	5.31	21.75	0.50
3:30 pm	6.70	8.86	22.56	10.57
3:50 pm	33.52	24.68	23.41	3.53
4:10 pm	34.38	28.38	28.97	5.75
Mean Difference	18.85	10.70	16.76	3.83
Standard Deviation	17.21	9.69	8.20	3.79
t calculated	3.286	3.313	6.130	3.030
Conclusion	reject H_o	reject H_o	reject H_o	reject H_o
Probability to Accept H_o $(1-\beta)$	———	———	———	———

Note : n = 9, $t_{(0.025,8)} = 2.306$

APPENDIX D-3

THE REGRESSION ANALYSIS RESULTS OF THE COMBINED DATA FOR EXCLUSIVE/PERMISSIVE AND EXCLUSIVE INTERSECTIONS

- Regression Analysis Results For Exclusive/Permissive Left Turn Phasing

Parameters	Near Side Approach		Far Side Approach	
	Left Turn	Through	Left Turn	Through
Slope Value	0.627	0.310	0.483	0.426
Std Error of Slope	0.201	0.051	0.281	0.076
Intercept Value	50.98	24.06	38.91	18.45
R Squared	0.172	0.443	0.059	0.400
t calculated	-1.853	-13.596	-1.839	-7.548
Conclusion	cannot reject H_o	reject H_o	cannot reject H_o	reject H_o
Probability to Accept H_o $(1-\beta)$	0.42	———	0.44	———

Notes : H_o: $b_1=1$ (slope is 45^o), H_a: $b_1=1$ (slope is not 45^o)
$n = 49$, $t_{(0.025,47)} = 2.014$

- Regression Analysis Results For Exclusive Left Turn Phasing

Parameters	Near Side Approach		Far Side Approach	
	Left Turn	Through	Left Turn	Through
Slope Value	0.863	0.134	1.122	0.369
Std Error of Slope	0.294	0.231	0.301	0.137
Intercept Value	40.66	36.75	17.67	24.10
R Squared	0.365	0.022	0.481	0.327
t calculated	-0.465	-3.740	0.407	-4.612
Conclusion	cannot reject H_o	reject H_o	cannot reject H_o	reject H_o
Probability to Accept H_o $(1-\beta)$	0.94	———	0.95	———

Notes : H_o: $b_1=1$ (slope is 45°), H_a: $b_1=1$ (slope is not 45°)
$n = 17$, $t_{(0.025,15)} = 2.131$

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