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ANALYSIS OF THE SAMPLE INTERVAL AND STUDY PERIOD USED TO CONDUCT DELAY STUDIES AT SIGNALIZED INTERSECTIONS

Prepared by:
Roger L. Hatton
Traffic Engineer
Traffic Engineering Section
Arizona Department of Transportation

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Arizona Department of Transportation
206 South 17th Avenue
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16. ABSTRACT

Traditionally traffic engineers have conducted intersection delay studies using a 13-second sample interval if the signal cycle is an even multiple of 15 seconds. A review of the literature does not indicate that this requirement is based on rigorous investigation.

This research used a data file and time-lapse film developed by W.R. Reilly, et. al. and supplied by the Federal Highway Administration. The data represents vehicle delay information collected at ten intersections in five states for a peak period and an off-peak period.

Using a FORTRAN computer program, the data were analyzed to determine the actual delay experienced on one approach of each intersection and the estimated delay for sample intervals of 5 through 30 seconds in one-second increments. Statistical analysis indicates no difference in the estimated delay values produced at the 0.01 level of significance. A 15-second sample interval is recommended for use in conducting stopped-time delay studies at signalized intersections under all signal modes.

Using a 15-second sample interval the length of the study period for conducting delay studies was also analyzed. No statistical difference was found in the accuracy of the estimated delay values produced using study periods of 300 through 2700 seconds at the 0.01 level of significance. A regression analysis of the standard deviation and the mean sample size of the data indicates a linear relationship between them. Using this linear relationship minimum and desirable vehicle volume sample sizes were calculated. A recommendation is made to base the length of the study period on the minimum sample size that will produce the expected error that is appropriate for the study being made.

17. KEY WORDS
Intersection Delay, Stopped-Time Delay, Approach Delay, Time-Lapse Photography, Statistical Analysis, Linear Regression, Analysis of Variance

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INTRODUCTION

General Discussion

A primary means of evaluating the effectiveness of traffic controls at an intersection is the measurement of vehicle and pedestrian delay at the intersection. Delay is defined as time lost because of traffic frictions and traffic control devices and is usually expressed in seconds per vehicle.(1)

One method of measuring intersection delay and intersection performance is to measure stopped-time delay. Stopped-time delay is defined as the component of delay during which the vehicle or pedestrian is actually standing still.(2) Stopped-time delay can be measured for vehicles and pedestrians at intersections under traffic signal control, stop or yield sign control, or without control. Since, most stopped-time delay studies are conducted at intersections under traffic signal control, this research was limited to analyzing stopped-time delay parameters at signalized intersections.

The most common method used by traffic engineering organizations to measure stopped-time delay is the manual method.(3) The manual method of measuring stopped-time delay requires the counting of vehicles or pedestrians during a pre-selected sample interval such as 13 seconds for traffic signals operating in a pre-timed mode or system mode and 15 seconds for actuated traffic signals not operating in a system.(4)

Problem Statement

The traditional precept of traffic engineers has been for many years that a sample interval other than 15 seconds must be used when conducting a delay study if the signal cycle is an even multiple of 15 seconds. Reilly, et.al., recommended using a 13-second sample interval when a signal is operating in a pre-timed or system mode for cycle lengths of 45, 60, 75, 90, 105, 120, 135, or 150 seconds.(5)

It has been assumed that if the cycle is an even multiple of 15 seconds the point sample will be taken at the same position in the cycle each time a point sample is recorded, thus biasing the sample. To prevent the point sample from being taken at the same position in the cycle a 13-second interval is usually used.

For studies using a 15-second interval between samples the procedure is relatively simple. Point samples are taken at 0, 15, 30, and 45 seconds using the sweep hand of a stopwatch. However, when a 13-second interval is used the procedure becomes much more complicated because readings are required at odd times, i.e., 0, 13, 26, 39, 52, 05, 18, 31, 44, 57, and 10 seconds. Thus, an interval timer must be used to give an audible sound to identify when a point sample is to be taken. If a 15-second or other convenient interval could be used under all traffic signal operating modes, manual stopped-time delay studies would be considerably simplified with less chance of error.

A review of the literature does not indicate that a rigorous study was conducted to determine that a 13-second interval is required when conducting a stopped-time delay study when a traffic signal is operated in a pre-timed or system mode with a cycle an even multiple of 15 seconds.

Since the sampling interval is a significant aspect of the stopped-time delay study it would seem reasonable that the "best" interval should be selected. Therefore, this research project was undertaken to determine the "best" sampling interval for stopped-time delay studies. The "best" sampling interval is one which is convenient and economical to use and produces an accurate estimate of the stopped-time delay experienced at a signalized intersection. Statistically the "best" sampling interval is one that produces results that are significantly more accurate than all other intervals studied.

Significant resources are required to conduct stopped-time delay studies, therefore, the length of time required to complete a study becomes important. The length of the study or study period was also analyzed as a part of this research project.

Research Objectives

Since the literature does not indicate that the current recommended sampling intervals are based on rigorous study, this research project was undertaken to determine the "best" sampling interval for conducting stopped-time delay studies. Since the resources required to conduct delay studies are significant, the length of the study period was also analyzed to determine the optimal study length. The optimal study length or "best" study period is one which statistically produces an estimate of the stopped-time delay experienced at a signalized intersection which is more accurate than all other periods studied. Desirably, the "best" study period will also be the shortest or most economical period which will produce an accurate estimate of the stopped-time delay. The objectives of the research were to:

1. Compare the estimated stopped-time delay, by incrementing the interval by one second through a range of sample intervals of 5 to 30 seconds, to the actual observed stopped-time delay for a peak period and an off-peak period at ten signalized intersections.
2. Compare the estimated stopped-time delay to the actual observed stopped-time delay for study periods of 300 to 2700 seconds at ten signalized intersections using an increment of 300 seconds.
3. Using the data from objectives Nos. 1 and 2 recommend the "best" sampling interval and the "best" study period for conducting stopped-

time delay studies at signalized intersections.

4. Recommend areas for additional research vis-a-vis stopped-time delay studies.

Research Approach and Limitations

The purpose of this research project was to determine the "best" sampling interval and study period for use in measuring delay at signalized intersections. To accomplish the purpose of this research it was necessary to analyze the delay that was experienced at a number of signalized intersections. The only practical way to accomplish the large number of observations was through the use of time-lapse photography.

The Federal Highway Administration (FHWA) provided copies of time-lapse film and the data tape which were produced under FHWA Contract No. DOT-FH-11-8836 and reported in three volumes: "A Technique for Measurement of Delay at Intersections", Vol. 1, Technical Report, Report No. FHWA-RD-76-135; "A Technique for Measurement of Delay at Intersections", Vol. 2, Data Summaries, Report No. FHWA-RD-76-136 and "A Technique for Measurement of Delay at Intersections, Vol. 3, User's Manual, Report No. FHWA-RD-76-137. The data used in this research were limited to the data supplied by the FHWA.

The delay data were extracted from time-lapse film shot at ten signalized intersections located in the states of Massachusetts, Virginia, Maryland, Oklahoma, and Arizona.

Diagrams of the intersections studied are shown in Figures A-1 through A-10 in Appendix A.

The research approach used in conducting the research project is depicted in Figure 1, Flow Diagram For Research Project.

Significance of Research

Stopped-time delay studies are used to:

*estimate the environmental effects of vehicles such as air and noise pollution;

*evaluate intersection control techniques;

*determine road user costs, e.g., time, fuel, tire wear;

*evaluate pedestrian-related delays;

*determine the need for traffic control devices; and

*evaluate intersection capacity.

Since delay is a measure of intersection performance it is reasonable to assume that stopped-time delay studies are used by traffic engineers worldwide. Therefore, the results of this research can have worldwide significance.

The time stopped at an intersection is the time most readily perceived by a driver. Also it is one of the easiest parameters of intersection approach characteristics to measure. Therefore, it is desirable to be able to measure stopped-time delay by using the "best" sampling interval possible. This will allow traffic engineers to

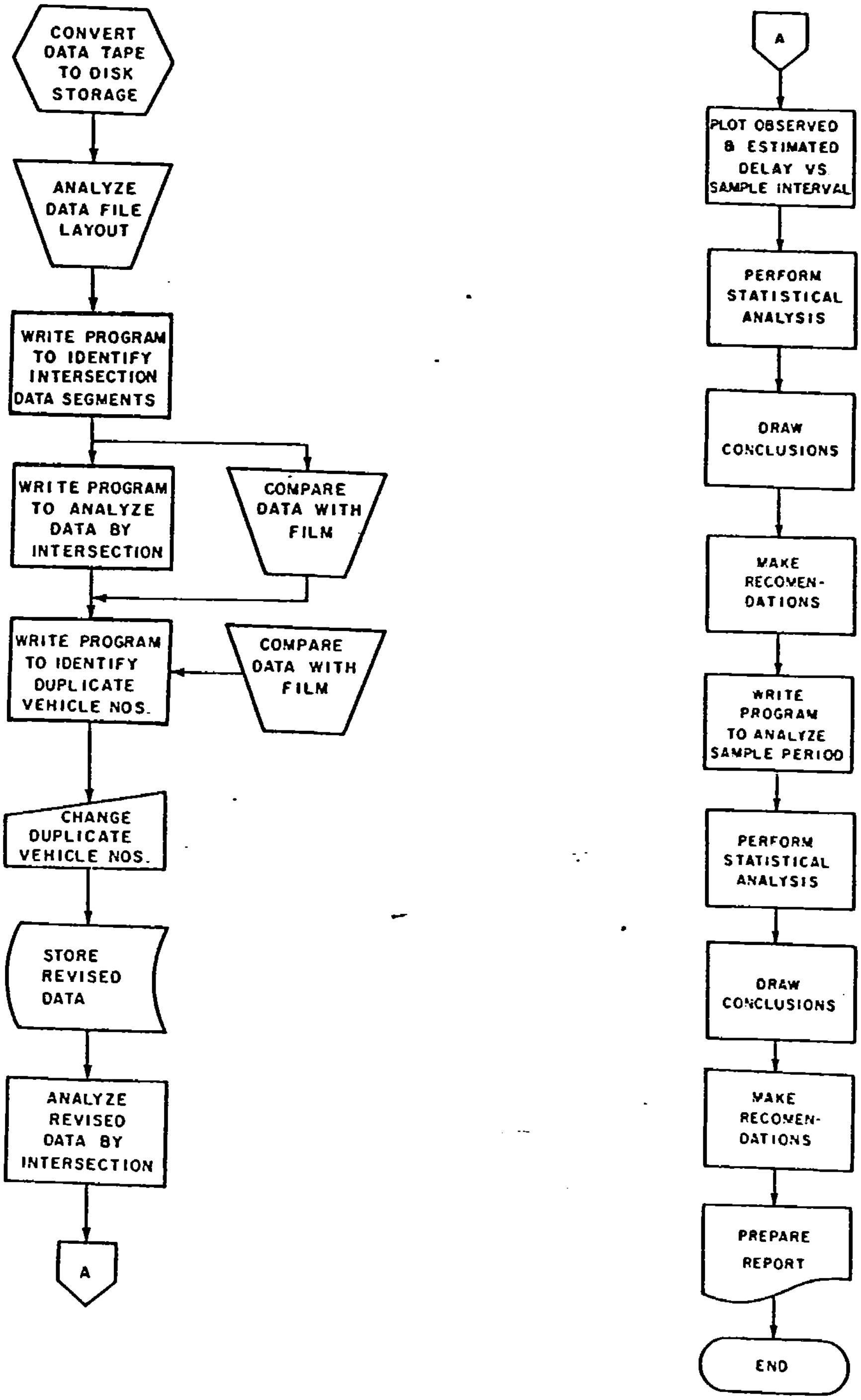

Figure 1. Flow Diagram for Research Project

reduce the amount of time the driver is required to stop by monitoring the intersection performance.

If the results of this research project indicate that there is no statistical difference in the sample interval when the estimated stopped-time delay is compared to the actual observed average stopped-time delay at ten signalized intersections, there is no necessity to conduct stopped-time delay studies using 13 seconds when the signal cycle is an even multiple of 15 seconds. The ability to use a 15 second sample interval for all stopped-time delay studies can have a significant impact on the ease of conducting studies and eliminate the need for special equipment, thus, reducing the cost of conducting delay studies.

Since vehicle delay, expressed as "stopped delay per vehicle," is the parameter used in the new signalized intersection capacity method (5) to determine the level-of-service, the sample interval and the length of the study period takes on added significance.

Stopped-time delay provides a means to evaluate how well a signalized intersection operates. Thus, this research will provide significant knowledge to more efficiently evaluate this important parameter.

This research is relevant to and should add to the body of knowledge produced by recent intersection research conducted in Arizona. These research projects are:

1. Evaluation of Driver Behavior at Signalized Intersections,

2. Optimization of Traffic Signal Change Interval, and
3. Development of Data Measurement Technique for Traffic Operations Analysis at Intersections.

One means of evaluating the significance of research is to relate it to past research. Thus, a review of previous research through a review of literature can chronicle significant past research which relates to the present research project.

Notes

(1) Box, Paul C. and Joseph C. Oppelander, Ph.D. Manual of Traffic Engineering Studies 4th Ed. (Arlington, Virginia: Institute of Transportation Engineers, 1976), p. 106.

(2) Ibid.

(3) Ibid., p. 109.

(4) Reilly, W. R., C. C. Gardner, and J. H. Kell A Technique for Measurement of Delay at Intersections, Vol. 3, User's Manual, Report No. FHWA-RD-76-137 (Washington D.C.: Federal Highway Administration, Sept. 1976), p. 7.

(5) Ibid.

(6) JHK and Associates and the Traffic Institute, Northwestern University, NCHRP Signalized Intersection Capacity Method, Feb. 1983.

CHAPTER II

REVIEW OF LITERATURE

Previous Research

A review of the literature reveals that as early as 1934 Greenshields(1) studied vehicle flow characteristics on intersection approaches. This was one of the earliest uses of 16mm motion photography to investigate traffic delays at intersections. The use of a desk calculator in collecting vehicle delay data at intersections was reported by Rivett(2) in 1940.

In the early 1950's, Berry(3),(4),(5) completed some of the most important work in the field of measuring delay at intersections and travel times. Berry's work was the cornerstone for the volume-density method of measuring travel time reported by Solomon(6) in 1957.

Speed and delay are integral parts of highway and intersection capacity. However, speed is of little use in evaluating a particular intersection. Level-of-service is the general index used to measure the relative operational efficiency as recommended in the Highway Capacity Manual.(7)

The Highway Capacity Manual (HRB SR 87) uses the "load factor" as a surrogate for delay to evaluate the operational efficiency of signalized intersections. The load factor is defined as the percentage of fully utilized green phases within the peak hour. The use of the load factor as a measure of delay was in question and in 1968, May and Pratt(8) correlated level-of-service, load factor, and average delay in seconds per vehicle using a simulation model.

May and Pratt recommended that the load factor limits be revised to provide for more consistent results. Additional research into the relationships between cycle failure rate, load factor, and delay was conducted by Sagi and Campbell(9) in 1969 and Tidwell and Humphreys(10) in 1970.

Buehler, et. al.,(11) studied the relationship of sampling queue backup and delay at signalized intersections and evaluated this relationship as a level-of-service indicator for intersection performance. The Buehler study used time-lapse photography to study four urban intersections under pre-timed signal control. Simultaneously, field observations of the queue length were made at 10-second intervals. Buehler concluded that field sampling of queue backup was much simpler to use than field sampling of stopped-time delay.

King and Wilkinson(12) used expected delay and approach capacity as measurements to evaluate signal configurations and lens size effectiveness. Robertson and Berger(13) developed a manual procedure for conducting stopped-time delay studies. The procedure known as the Berger-Robertson Method is based on several established mathematical and traffic engineering relationships. The method assumes that an estimate of a continuous function can be approximated by a linear fit over any sufficiently small interval. The second assumption made is that if a linear equation is adequate the center or mean volume represents the best least square estimate of the values contained in the region of that line. The last assumption is that the earlier arriving vehicles in any one lane are released from the queue first.

The Berger-Robertson procedure is to divide the cycle length into a sufficient number of small equal intervals, e.g., five seconds. Then the vehicles that stop in each sample interval are counted and recorded. The midpoint of the interval is assumed to represent the average arrivals of the vehicles in the interval. The number of previously stopped vehicles departing, i.e., clearing the intersection, is also tallied by interval. The departure of these vehicles is assumed to be randomly distributed in the interval. The results of the manual procedure were compared to the delay found by using time-lapse photography and the statistical analysis indicated a very close correlation. The Berger-Robertson method has some of the same qualities as the point sample method of conducting stopped-time delay studies developed by Reilly, et. al.(14)

The point sample method uses a sample interval of 15 seconds or 13 seconds if the signal cycle length is an even multiple of 15 seconds. The procedure involves counting the number of stopped vehicles on a particular intersection approach at 15-second intervals for a given minimum period of time, usually 60 point samples or more.

A complete description of the Intersection Delay Study procedure developed by Reilly, et. al.,(15) can be found in Appendix B.

Although the research literature on traffic flow characteristics spans 50 years there is no indication that a rigorous investigation of the stopped-time delay sampling interval has been conducted. The most significant research done in this area in recent years was conducted by Reilly et. al., in 1976. Therefore, William Reilly was contacted and, based on his knowledge, he confirmed the finding that the sample interval used for conducting stopped-time delay studies had not been rigorously studied.

Bibliography

An adjunct of reviewing the relative literature was the opportunity to develop a fairly comprehensive bibliography. This task was aided immeasurably by the computer search of relevant subjects by the Transportation Research Information Service. A bibliography of selected relevant works is contained in the section titled "BIBLIOGRAPHY".

Notes

(1) Greenshields, Bruce D. "A Photographic Method of Investigating Traffic Delays," Proceedings, Michigan Highway Conference, 1934.

(2) Rivett, Irving "A Simple Method For Tabulating "Traffic Delay," Traffic Engineering, Sept. 1940.

(3) Berry, D. S. "Evaluation of Techniques for Determining Overall Travel Time," Proceedings. 31 Annual HRB

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(6)Solomon, David "Accuracy of the Volume-Density Method of Measuring Travel Time," Traffic Engineering, March 1957, pp. 261, 262, and 288.

(7)Highway Capacity Manual, HRB SR 87, 1965.

(8)May, Adolf Jr., and David Pratt, "A Simulation Study of Load Factor at Signalized Intersections," Traffic Engineering, Feb. 1968, pp. 44-49.

(9)Sagi, George S., and Campbell, Lowell R., "Vehicle Delay at Signalized Intersections: Theory and Practice," Traffic Engineering Feb., 1969, pp. 32-40.

(10)Tidwell, Jr., J. E. and J. B. Humphreys, "Relation of Signalized Intersection Level of Service to Failure Rate and Average Individual Delay," HRB Rec 321, 1970.

(11)Buehler, Martin, G., Thomas J. Hicks, Donald S. Berry "Measuring Delay by Sampling Queue Backup, "Transportation Research Record 615, 1976, pp. 30-36.

(12)King, Gerhart, F. and M. Wilkinson "Relationship of Signal Design to Discharge Headway, Approach Capacity, and Delay," Transportation Research Record 615, 1976, pp. 37-44.

(13)Robertson, H. Douglas and Wallace G. Berger "Berger-Robertson Method for Measuring Intersection Delay," Transportation Research Record 615, 1976, pp. 45-46.

(14)Reilly, W. R., C.C. Gardner, and J. H. Kell A Technique for Measurement of Delay at Intersections, Vol. 3, User's Manual, Report No. FHWA-RD-76-137 (Washington, D.C.: Federal Highway Administration, Sept., 1976).

(15)Ibid., pp. 6-16.

CHAPTER III

THE DATA FILE

Development of the Data File

The data file used in this research project was developed under Federal Highway Administration (FHWA) Contract No. DOT-FH-11-8836 and reported in three volumes: A Technique for Measurement of Delay at Intersections, Vol. 1, Technical Report, Report No. FHWA-RD-76-135; A Technique for Measurement of Delay at Intersections, Vol. 2, Data Summaries, Report No. FHWA-RD-76-136; and A Technique for Measurement of Delay at Intersections, Vol. 3, User's Manual, Report No. FHWA-RD-76-137. All future reference in this report, to this work, will be identified as the "previous stopped-time delay research or previous research".

The data were collected using time-lapse photography and reduced by using a frame counter/analyzer. A complete discussion of the procedures used can be found in Volume 1 of the previous research at Chapter 6, DATA COLLECTION AND REDUCTION.

The following is a brief summary of the procedures used. Ten study sites (see Appendix A) were selected and a schedule for filming one off-peak period and one peak period at each site was developed. A study period of 49 minutes, 30 seconds was used.

Filming was performed by two time-lapse cameras, one a

16mm camera running at 16 frames per second and the second camera was a Minolta Super 8 filming at a rate of one frame per second. All filming was done from buildings, either from the rooftop or from inside the building.

The data were reduced from the film by using a frame counter/ analyzer. Frame readings were taken for the following vehicle activities:

1. Enter approach delay section
2. Stop
3. Start
4. Leave approach delay section at the STOP line
5. Change lane
6. Enter approach delay section extraneously
7. Leave approach delay section extraneously
8. Any non-signal related stop

An "extraneous" vehicle is one which enters and/or leaves the approach delay section at other than the two normal section limits, i.e., the upstream start of the delay section and the STOP line. This would normally be a vehicle entering or leaving at a driveway.

In reducing the data the vehicles were first listed by signal cycle and by the lane from which they exited the approach. Then each vehicle was followed from the beginning of the upstream approach delay section until it exited from the study section, recording the events listed above. The film from the camera which produced the best product was used in the data reduction process. Thus, film shot at both one frame per second and 16 frames per second were used. The 16mm film was copied on 8mm film, therefore, all time-lapse film supplied to the Principal Investigator for use in this research was 8mm.

The data were recorded on pre-printed forms and later punched onto computer cards. The computer cards were then transferred to magnetic computer tape. The general information for the data file tape is shown in Table 1. The tape was provided to the Principal Investigator by the FHWA for use in the research project "Analysis of the Sample Interval and Study Period Used to Conduct Delay Studies at Signalized Intersections".

The magnetic computer tape was converted to magnetic disk storage and placed on the Digital VAX-11/780 research computer located in the Engineering Research Center at Arizona State University. The general information for the converted data file is shown in Table 2.

The next step in analyzing the data file was to review the file organization.

Data File Organization

The data file is organized into four record levels as shown in Table 3. Table 4 depicts the data file record layout. The record name, field name, field length, and the starting and ending character positions are shown in Table 4. This information was essential to be able to read the data file.

File Description:	Time-Lapse Photo-Analysis Frame Readings
Date:	
Tape Label:	"T-Lapse"
Computer System:	IBM-370 model 145 (DOS-VS)
Tape Density:	1600 bpi
No. of Tracks:	9 tracks
Record Size:	88 BYTES
Records Per Block:	150

Table 1. Date File (Tape) General Information

File Description:	Time-Lapse Photo-Analysis Frame Readings
File Name:	Delay.Old/Delay.New
Computer System:	Digital VAX-11/780
Operation System:	VMS Version 4.0 on node VMSA
Record Size:	88 BYTES
Records per Block:	150

Table 2. Data File (Disk) General Information

Record Level	Record Name	
1	A (File Header)	occurs 1 time
2	B (Segment Header)	occurs 20 times
3	C (Division Header)	occurs est. 200 times
4	D (Data Record)	occurs est. 21,000 times
4	F (Flag Record)	occurs est. 200 times

Table 3. Data File Record Structure

Record Name	Field Name	Field Length	Character Position		Character Type	Data Description
			Start	End		
A (File Header)	A1	4	2	5	A/N	Data Set Name
	A2	60	6	65	A/N	Data Set Description
	A3	8	81	88	A/N	Sequence Number "00000000"
B (Segment Header)	B1	2	1	2	N	Film No. (1 --- 20)
	B2	2	3	4	A	Direction of travel (NB, SB, EB, WB)
	B3	6	5	10	N	Filming Date
	B4	1	11	11	N	Day of Week(1 --- 7)
	B5	4	12	15	N	Begin Filming Time of Day
	B6	16	16	31	A/N	Study Approach Street Name
	B7	16	32	47	A/N	Intersection Street Name
	B8	16	48	63	A/N	City Name
	B9	16	64	79	A/N	State Name
	B10	8	81	88	N	Record Sequence Number
C (Division Header)	C1	2	1	2	N	Film Number (1 --- 20)
	C2	1	3	3	A	Part Code (A, B, C)
	C3	1	4	4	N	Leaving Lane No. (1 ---5)
	C4	2	6	7	N	Filming Rate (1, 16) fps
	C5	4	9	12	N	Free Flow Travel Time 1/10 secs.
	C6	8	81	88	N	Record Sequence Number
D (Data Record)	D1	2	1	2	N	Signal Cycle Number
	D2	4	3	6	N	Vehicle Number
	D3	5	7	11	N	Normal Enter Delay Section Frame Number
	D4	5	12	16	N	Vehicle Stopping Frame Number
	D5	5	17	21	N	Start after D4 Stop
	D6	5	22	26	N	Vehicle Stopping Frame Number
	D7	5	27	31	N	Start after D6 Stop
	D8	5	32	36	N	Normal Leave Section Frame Number
	D9	2	37	38	N	From Lane Number of D10 Lane Change
	D10	5	39	43	N	Lane Change Frame Number
	D11	2	44	45	N	From Lane Number of D12 Lane Change
	D12	5	46	50	N	Lane Change Frame Number
	D13	5	52	56	N	Leave Extraneously Frame Number
	D14	5	58	62	N	Enter Extraneously Frame Number
	D15	5	63	67	N	Number of Frames that the Vehicle was Stopped for Non-Signal Related Purpose
	D16	5	69	73	N	Number of Frames that the Vehicle was Stopped for Non-Signal Related Purpose
	D17	8	81	88	N	Record Sequence Number
F (Flag Record)	F1	4	1	4	N	"9996" to Mark End of Division Data "9996" to Mark End of Segment Data "9996" to Mark End of File
	F2	8	81	88	N	Record Sequence Number

Table 4. Data File Record Layout

Next a FORTRAN computer program was written to verify the organization. The output of this program was a listing showing the Record Count Number; the Segment Header Information: Film number, direction of travel, filming date, day of week, begin filming time of day, study approach street name, intersecting street name, city name, state name; the Division Header Information: Film number, part code (A,B,C), leaving lane number, filming rate (1, 16 fps), free flow travel time; and the Record Sequence Number of each record printed. The first record of the data file was not readable, therefore, it was deleted. This record contained the Data Set Name and the Data Set Description.

The data records were not read with this program, therefore, that information was not printed.

Next, the data records were reviewed.

Review of Data Records

Using the data file record layout information found in Table 4, a FORTRAN computer program was written to examine the pertinent elements of the data records. In addition to the Segment Header Information and Division Header Information the program produced the following listing from the data records. Signal Cycle Number, Vehicle Number, Enter Frame Number, Vehicle Stop Frame Number, Vehicle Go Frame Number, Vehicle Stop Frame Number, Vehicle Go Frame Number, (if more than two stops were made a second data record was used) Leave Section Frame Number, Extraneous Exit Frame Number, Extraneous Entry Frame Number, Non-Signal Stop

Frame Number, Non-Signal Stop Frame Number, and the Record Sequence Number. This computer program and the flow diagram were expanded later to aid in the analysis of the data.

If a vehicle stopped more than twice while traversing the approach study section a second data record, with the same vehicle number was created.

Due to the size of the data file, 21,990 records, it was not practical to run the complete data file all at one time. Therefore, the data file was divided into 20 samples representing the peak period data and off-peak period data for each of the 10 intersection approaches under study.

After the delay data were listed for each of the 20 samples a random sample of the data was compared to the time-lapse film. All of the records which were compared to the time-lapse film were found to be very accurate. Reilly, et. al., are to be congratulated for the accuracy of the data file which they developed.

Modification of Data Records

During the course of the analysis process it was discovered that when the original data file was developed each vehicle was identified by the film frame count number as the vehicle crossed the STOP line by individual lane. Thus, if four vehicles crossed the STOP line simultaneously all received the same vehicle number. This posed no problem for the original researchers since all of their analysis was done on an individual lane basis. However, the analysis for this research project was being done on an approach basis, i.e., all lanes were being studied at the same time. This duplication of vehicle numbers created a serious problem in determining the correct vehicle count since duplicate data records were created when a vehicle stopped more than two times. The duplicate data record was identified by the same vehicle number and these duplicate records had to be subtracted so that an over count of vehicles did not occur. However, when the number of duplicate vehicles was calculated the number was overstated because if two or more vehicles crossed the STOP line at the same time they were counted as duplicate vehicle numbers.

To solve this problem a FORTRAN computer program was written to identify and list all duplicate vehicle numbers. Then a physical search of the data lists was made to determine if it was a duplicate record because the vehicle stopped more than two times or if two or more vehicles had the same vehicle number. When it was determined that two or more vehicles had the same number the data file was modified to give each vehicle a unique vehicle number. A total of 3,545 vehicle numbers had to be changed. A summary of the data file modifications is shown in Table 5. Additional comparisons were made with the time-lapse film to verify the duplicate vehicle number changes.

During the process of examining the duplicate vehicle numbers thirty-three records were discovered that contained no usable data. These records were deleted.

Also during the analysis process sample 18, i.e., data

Film Number	Number of Records Deleted	Number of Data Records Changed	Number of Vehicle Numbers Changed
1	0	0	69
2	1	0	36
3	0	0	150
4	0	0	73
5	2	0	357
6	0	0	60
7	0	0	99
8	2	0	70
9	0	0	127
10	13	0	152
11	0	0	503
12	3	0	183
13	0	0	367
14	1	0	128
15	2	0	484
16	6	1	303
17	0	0	145
18	3	1	70
19	0	0	97
20	0	0	72
Total	33	2	3,545

Table 5. Summary of Data File Modifications

from Film Number 18, produced actual average delay per stopped vehicle and average delay per approach vehicle which was approximately 34 percent lower than the estimated average delay.

A detailed analysis of the data listing for sample 18 revealed that a vehicle go frame number had been recorded as 3536 instead of 35036. However, correcting this record made the results even worse than before. This indicated that a second offsetting error existed.

Another detailed analysis of the data listing for sample 18 revealed that the vehicle stop frame number for one record had been omitted.

Thus a very large negative value was generated which offset the large positive value which had been generated by the previous error.

This error was corrected, however, when the length of the study period was analyzed. Sample 16 was found to have a total study period length of 6,204 seconds. Since the maximum length of the study period should not exceed 2,970 seconds there was an obvious error.

The length of the study period is calculated by determining the leave section frame number of the last vehicle to leave the approach study section during the study period and dividing by the filming rate in frames per second. However, the original computer program used the difference between the smallest vehicle stop frame number and the largest vehicle go frame number divided by the filming rate in frames per second. Thus, the error was found by a detailed examination of the vehicle go frame number listing for sample 16.

Two errors were found in one data record. The vehicle stop frame number and the vehicle go frame number were recorded as 88328 and 99342 respectively instead of 8328 and 9342. The first digit of each number had been erroneously repeated. The error was corrected by deleting the first digit of each number. This correction completed the modifications to the data file.

The modified data file was identified by the file name DELAY.NEW;1 and the original data file was identified as DELAY.OLD;1. As indicated above the data file was divided into 20 samples and each subfile was identified by the file name DELAY X. DAT;1 where the value of X was the film number of the sample.

This completed the analysis of the data file, and the next phase of the research was the analysis of the data. The data analysis was divided into two phases. The first phase of the analysis looked at the "best" sample interval for conducting stopped-time delay studies at signalized intersections.

CHAPTER IV

ANALYSIS OF THE SAMPLE INTERVAL USED TO CONDUCT STOPPED-TIME DELAY STUDIES

Introduction

The procedure, developed by Reilly, et. al.,(1) for conducting intersection delay studies requires that

> if a signal is operating in a pre-timed or system mode, use a 13-second interval for cycle lengths of 45, 60, 75, 90, 105, 120, 135, or 150 seconds. For all other cycle lengths in a pre-timed or system mode, use a 15-second interval between samples. For all traffic actuated signals not operating in a system, use a 15-second interval.(2)

For a complete description of the intersection delay study procedure refer to Appendix B.

Since the literature does not indicate that the length of the interval between point samples was determined by rigorous study this research was undertaken to determine the "best" sample interval for conducting stopped-time delay studies. To provide the greatest opportunity to select the "best" sample interval it was decided to analyze the delay data by comparing the estimated stopped-time delay to the actual stopped-time delay observed at the ten study sites by incrementing the sample interval by one second from 5 seconds to 30 seconds.

The data analysis was accomplished by using a FORTRAN computer program which was used to compare the data and listed the essential statistics derived from the data file. Using these statistics the estimated average stopped-time delay per stopped vehicle was calculated and plotted for each sample interval, i.e. 5 seconds, 6 seconds, ..., 30 seconds. Super-imposed on this plot is a plot of the actual observed stopped-time delay for the particular study approach. A typical plot can be found in Appendix C. Similar plots were produced for the estimated average stopped-time delay per approach vehicle. A typical plot is in Appendix D.

Next a statistical analysis of the data was performed using the Statistical Analysis System (SAS) and the Statistical Package for the Social Sciences (SPSS-X).

The first activity in analyzing the data was the development of a computer program to compare the estimated stopped-time delay to the actual stopped-time delay.

Development of the Computer Program

The development of the FORTRAN program which was used to analyze the data file was discussed in Chapter III. This program provided the basic data listings from the data file, therefore, the next step was to expand the program to perform the data analysis.

The first step in the expansion of the computer program was to devise a method of determining when a vehicle was stopped during a given point sample. The fact that all vehicle data were recorded in sequence by cumulative photo frame count number could be used to develop a procedure to determine if a vehicle was stopped during a point sample. A reference value that could be compared to the Vehicle Stop Frame Number and the Vehicle Go Frame Number and could be incremented over the range of the sample intervals to be studied was required. The method used to develop a reference value was to convert the study sample interval to an equivalent number of frames, i.e., 16fps X 5-second sample interval = 80 frames.

This interval or reference value was then compared to the Vehicle Stop Frame Number and the Vehicle Go Frame Number. If the Stop Frame Number is less than the interval value and the Vehicle Go Number is larger than the interval value, the vehicle is stopped for that point sample. All of the data in the data file is compared to that interval value and then the sample interval is increased by one second and the procedure is repeated. This process is repeated 26 times until the program reaches the maximum sample interval which was established at the start of the terminal session.

The program was designed so that the user is queried by the terminal for the starting interval, the ending interval, and the increment to be used in the analysis. Therefore, the program will accept variable starting and ending intervals and increments.

Since the data file was subdivided into 20 subdata files the user was also queried for the specific data file name, i.e. DELAY X.DAT, and the output file name for each sample.

Stopped-time delay studies are conducted and reported in terms of the number of stopped vehicles on the study approach and the total number of vehicles on the approach, i.e., the average delay in seconds per stopped vehicle or the average delay in seconds per approach vehicle.

To determine the number of vehicles on the approach a count was made of the vehicle records as they were read. However, since duplicate records were made when a vehicle stopped three times or more while traversing the study section, these duplicate records were counted and subtracted from the total.

In this analysis all vehicles were counted regardless of how they entered or left the study section. This differs from the previous research since they excluded from the approach vehicle count those vehicles that exited from the study section extraneously. Since all vehicles on the approach contribute to the delay it was concluded that all of the vehicles should be counted. Therefore, the total approach volumes and the average delay values found in this research will differ slightly from the values reported in the previous research. The number of vehicles which stopped is determined by counting the number of records with zeroes in the Vehicle Stop Frame Number position and subtracting that total from the total number of vehicles on the approach.

The estimated stopped-time delay for the approach is calculated by multiplying the total number of stopped vehicles which were counted for each sample interval by the value of the sample interval in seconds, i.e., 5, 6, 7, ..., 30 seconds. To determine the estimated average stopped-time delay per stopped vehicle or per approach vehicle the previous value is divided by the total number of vehicles which stopped or the total number of vehicles on the approach which were counted for the study sample interval.

Since it was desired to compare the estimated stopped-time delay to the actual observed stopped-time delay the computer program had to be capable of calculating the actual time all vehicles on the study approach were stopped. This is accomplished by subtracting the vehicle stop frame number from the vehicle go frame number and summing all of the values. This value is divided by the filming rate, i.e., 1 fps or 16 fps, to give the total stopped-time delay in seconds for the total study period. To determine the averaged stopped-time delay per stopped vehicle or per approach vehicle the total stopped-time delay value is divided by the appropriate total number of vehicles.

The following is a description of the output produced by the FORTRAN computer program used to perform the data analysis of the sample interval.

Computer Program Output

The computer program output was divided into five sections. Segment information, division information, data information, the general data for the approach study section, and the output data for each sample interval.

The output information is as described in Chapter III except as discussed below.

The Division Header Information and Data Header Information is repeated at the start of the data listing for each lane and at the start of the data listing for each part, i.e., each 49 minute, 30 second filming segment is divided into three parts, A, B, and C, each representing 16 minutes, 30 seconds of real-time.

Next, various categories of duplicate vehicle numbers were identified and listed:

Duplicate Veh Nos. (two records with the same vehicle number)
Multiple Veh. Nos. (three or more records with the same vehicle number)
Duplicate Veh Nos. With Different Enter Frame Nos.
Duplicate Veh Nos. Entering Study Section
Duplicate Veh Nos. Leaving Study Section

All of these duplicate vehicle numbers were eliminated except the first category, Duplicate Veh Nos., which identified multiple vehicle records when a vehicle stopped three or more times while traversing the study section. For a discussion of this activity refer to the Section, Modification of Data Records in Chapter III.

Next the general data information for the approach study section was listed:

Film No.: 1, 2, ..., 20
Direction of Travel: NB, SB, EB, or WB
Filming Date

Day of Week

Time of Day Filming Started

Study Approach Street Name

Intersecting Street Name

City Name

State Name

Number of Duplicate Vehicle Numbers

Number of Vehicles in Study Section at Start of Filming

Number of Vehicles in Study Section at End of Filming

Number of Vehicles on Approach

Number of Vehicles Entering Study Section Normally

Number of Vehicles Leaving Study Section Normally

Number of Vehicles Entering Study Section Normally With Identical Vehicle Numbers: (should be zero)

Number of Vehicles Leaving Study Section Normally With Identical Vehicle Numbers (should be zero)

Number of Vehicles Entering Extraneously

Number of Vehicles Leaving Extraneously

Number of Vehicles Entering Extraneously With Identical Vehicle Numbers: (should be zero)

Number of Vehicles Leaving Extraneously With Identical Vehicle Numbers: (should be zero)

Number of Vehicles Not Stopping

Number of Vehicles Stopping

Study Period

Next the output data for each study sample interval were listed:

Film No.
Study Approach Street Name
Intersection Street Name
City Name
State Name
Number of Vehicles Observed in Study Sample
Study Sample Interval Used: 5 seconds, 6 seconds, ..., 30 seconds
Estimated Total Stopped-Time Delay
Estimated Average Delay Per Stopped Vehicle
Estimated Average Delay Per Approach Vehicle
Observed Total Stopped-Time Delay
Observed Average Delay Per Stopped Vehicle
Observed Average Delay Per Approach Vehicle

Next, the output data were summarized and analyzed.

Output Data and Analysis

The first analysis of the output data was a summarization of the study section volume data which is shown in Table 6. This volume data summary revealed some interesting information.

The percentage of the approach volume leaving the study section extraneously ranged from a low of 0.2% (2 vehicles) to a high of 16.3% (186 vehicles). The percentage of

Film No.	No. of Veh. in Study Section	No. of Veh. Leave Study Section Normal	% Leave Normal	No. of Veh. Leave Study Section Extran	% Leave Extran	No. of Veh. Stop	% Stop	No. of Veh. No Stop	% No Stop
1	807	767	95.0	40	5.0	673	83.4	134	16.6
2	651	596	91.6	55	8.4	526	80.8	125	19.2
3	1008	996	98.8	12	1.2	146	14.5	862	85.5
4	689	665	96.5	24	3.5	114	16.5	575	83.5
5	1817	1783	98.1	34	1.9	941	51.8	876	48.2
6	579	540	93.3	39	6.7	68	11.7	511	88.3
7	1141	955	83.7	186	16.3	828	72.6	313	27.4
8	891	752	84.4	139	15.6	590	66.2	301	33.8
9	845	829	98.1	16	1.9	717	84.9	128	15.1
10	754	738	97.9	16	2.1	545	72.3	209	27.7
11	1622	1556	95.9	65	4.1	1214	74.8	408	25.2
12	944	839	88.9	105	11.1	569	60.3	375	39.7
13	1843	1840	99.8	3	0.2	1416	76.8	427	23.2
14	950	948	99.8	2	0.2	656	69.1	294	30.9
15	1859	1805	97.1	54	2.9	1312	70.6	547	29.4
16	1340	1227	91.6	113	8.4	866	64.6	474	35.4
17	951	894	94.0	57	6.0	603	63.4	348	36.6
18	618	588	95.1	30	4.9	327	52.9	291	47.1
19	1075	966	89.9	109	10.1	239	22.2	836	77.8
20	857	826	96.4	31	3.6	183	20.9	674	79.1

Table 6. Summary of Study Section Volume Data

vehicles stopping ranged from a low of 11.7% (68 vehicles) to a high of 84.9% (717 vehicles). This data provided an insight into the variable character of study sections used.

A further indication of the variable character of the study sections is found in Table 7, Summary of Study Approach Volume/ Physical Data. This summary provides information on the number of approach lanes, exclusive left and right turn lanes, etc.

The next phase of the data analysis process was to plot the estimated average stopped-time delay per stopped vehicle for each study sample interval, i.e., 5 seconds to 30 seconds. For comparison purposes the actual observed average stopped-time delay was overlayed on this plot. See Appendix C.

These data were plotted using the SAS Procedure GPLOT. The actual plotting was done on a Versatec Graphics Plotter.

A review of these plots shows that the estimated stopped-time delay varies above and below the actual observed stopped-time delay. The magnitude of the variance of the estimated delay increases as the sample interval increases. This suggests that the "best" study sample interval will be the smallest sample interval.

Similar plots were produced for the estimated stopped-time delay per approach vehicle. A sample plot is in Appendix D.

To determine the "best" study sample interval a statistical analysis was necessary.

FILM NO.	NO. APPR LANES	EXCL LT LANE	EXCL RT LANE	NO. THRU LANES	APPR VOL	APPR VOL PER APPR LANE	APPR VOL PER THRU LANE	LT VOL*	THRU VOL*	THRU VOL PER THRU LANE	RT VOL*	% VEH STOP	SIGNAL CYCLE MULTIPLE 15 SEC
1	3	YES	YES	1	807	269	807	112	342	342	316	83.4	NO
2	3	YES	YES	1	651	217	651	162	218	218	216	80.8	NO
3	2	NO	NO	2	1008	504	504	55	931	466	0	14.5	YES
4	2	NO	NO	2	689	345	345	56	610	305	0	16.5	NO
5	4	NO	NO	4	1817	454	454	0	1758	440	10	51.8	NO
6	4	NO	NO	4	579	145	145	0	516	129	19	11.7	NO
7	2	NO	NO	2	1141	570	570	24	906	453	12	72.6	NO
8	2	NO	NO	2	891	446	446	22	713	357	16	66.2	NO
9	4	YES	NO	3	845	211	282	122	404	135	301	84.9	NO
10	4	YES	NO	3	754	189	251	124	395	132	206	72.3	NO
11	4	YES	NO	3	1622	406	541	174	1357	452	10	74.8	NO
12	4	YES	NO	3	944	236	315	161	628	209	46	60.3	NO
13	4	YES	YES	2	1843	461	614	28	1512	756	301	76.8	NO
14	4	YES	YES	2	950	238	475	118	699	350	128	69.1	NO
15	5	YES	YES	3	1859	372	620	54	1597	532	152	70.6	YES
16	5	YES	YES	3	1340	268	447	92	967	322	178	64.6	YES
17	4	YES	NO	3	951	238	317	145	657	219	86	63.4	NO
18	4	YES	NO	3	618	155	206	86	468	156	60	52.9	NO
19	3	YES	NO	2	1075	358	538	43	866	433	57	22.2	YES
20	3	YES	NO	2	857	286	429	27	772	386	21	20.9	YES

*VOLUMES FROM REPORT NO. FHWA-RD-76-136

Table 7. Summary of Study Approach Volume/Physical Data

Statistical Analysis

The analysis of the data from this research presented a problem since there were no replications of the observations at each intersection. However, a two-factor factorial analysis of variance (ANOVA) can be performed with only one observation per cell if there is no interaction within the main effects(3), i.e., the interaction effect of the model

$$Y_{ij} = M+T_i+B_j+(TB)_{ij}+E_{ij}$$

Where: $i = 1,2,...,a$

$j = 1,2,...,b,$

Y_{ij} = Observation taken under the ith level of factor A and the jth level of factor B

M = the overall mean effect

T_i = the effect of the ith level of the row factor A

B_j = the effect of the jth level of column factor B

$(TB)_{ij}$ = the effect of the interaction between T and B

E_{ij} = a random error component

is equal to zero. When there is no interaction the model becomes

$$Y_{ij} = M+T_i+B_j+E_{ij}$$

Where: $i = 1,2....,a$

$j = 1,2....,b$

Assuming that the analysis of variance (ANOVA) could be used without replication, the data to be analyzed had to be determined. Since the stopped-time delay procedure is a means of estimating the actual stopped-time delay which occurs at a given intersection, the best estimate occurs when the difference between the estimated value and the actual delay is zero. Thus, the logical statistic to test is the value of the difference between the estimated stopped-time delay and the actual observed stopped-time delay for the range of study sample intervals used at each of the study intersections.

Table 8 contains the results of subtracting the actual observed delay value in seconds per stopped vehicle from the estimated delay in seconds per stopped vehicle. Table 9 contains the results of subtracting the actual observed delay value in seconds per approach vehicle from the estimated delay in seconds per approach vehicle.

Appendix E contains a typical example of the results of the SAS General Linear Models Procedure (PROC GLM) with a plot of the residuals vs. the sample interval, a plot of the residuals vs. the sample (film number), a plot of the residuals vs. Y (Yhat, the fitted values), a normal probability plot, and a frequency bar chart of the residuals. ANOVAs and plots were prepared for the peak period data, the off-peak period data, and the peak period and off-peak period data combined, i.e., all data. The ANOVAs and plots were prepared for data based on the average delay per stopped vehicle and the average delay per approach

SAMPLE INTERVAL SECONDS	$\overline{X}$	s	s^2
5	-0.0360	0.101	0.010
6	0.0395	0.222	0.049
7	-0.0120	0.109	0.012
8	-0.0080	0.203	0.041
9	-0.0355	0.205	0.042
10	-0.0620	0.231	0.054
11	-0.0135	0.257	0.066
12	-0.0775	0.494	0.244
13	0.0490	0.475	0.225
14	0.0025	0.254	0.065
15	-0.1010	0.667	0.445
16	-0.0185	1.181	1.394
17	-0.2140	0.444	0.198
18	0.1190	0.697	0.487
19	0.1050	0.476	0.227
20	-0.1340	1.486	2.210
21	-0.2030	0.541	0.293
22	-0.2360	0.576	0.332
23	-0.1930	0.551	0.304
24	-0.1185	0.698	0.487
25	-0.3760	1.660	2.755
26	-0.0195	0.828	0.685
27	-0.0260	0.848	0.719
28	-0.0905	0.670	0.449
29	0.0740	0.901	0.811
30	-0.2010	1.185	1.405

Table 8. Analysis of Sample Interval - Estimated Minus Actual Average Delay per Stopped Vehicle in Seconds

SAMPLE INTERVAL SECONDS	$\bar{X}$	S	S^2
5	-0.0145	0.050	0.003
6	-0.0065	0.064	0.004
7	-0.0140	0.066	0.004
8	-0.0215	0.076	0.006
9	-0.0025	0.067	0.004
10	-0.0235	0.123	0.015
11	-0.0120	0.125	0.016
12	-0.0580	0.150	0.023
13	-0.0020	0.221	0.049
14	-0.0235	0.102	0.010
15	-0.0475	0.218	0.048
16	-0.0410	0.275	0.076
17	-0.0665	0.200	0.040
18	+0.0590	0.254	0.065
19	-0.0050	0.195	0.038
20	-0.0675	0.486	0.236
21	-0.1250	0.334	0.112
22	-0.0710	0.324	0.105
23	-0.1145	0.310	0.096
24	-0.1150	0.308	0.095
25	-0.1550	1.228	1.507
26	-0.0040	0.290	0.084
27	+0.0190	0.421	0.177
28	-0.0145	0.318	0.101
29	+0.0190	0.381	0.145
30	-0.0775	0.401	0.161

Table 9. Analysis of Sample Interval - Estimated Minus Actual Average Delay Per Approach Vehicle in Seconds

vehicle.

The Tukey test for additivity (interaction) was used to verify that there was no interaction and that a two-factor factorial ANOVA is possible. The Tukey test was performed using a SPSS-X Program. An example of the results are in Appendix E.

The assumptions underlying the analysis of variance are that data are adequately described by the model

$$Y_{ij} = M+T_i+B_j+E_{ij}$$

Where: $i = 1,2,\ldots,a$

$j = 1,2,\ldots,b$

Y_{ij} = Observation taken under the ith level of factor A and the jth level of factor B

M = the overall mean effect

T_i = the effect of the ith level of the row factor A

B_j = the effect of the jth level of column factor B

E_{ij} = a random error component

and that the errors are normally and independently distributed with mean zero and constant variance.(4) These assumptions were satisfied by inspecting the SAS plots (See example in Appendix G) except for the plot of the residuals vs. the interval which indicated a slight increasing pattern. This was not unexpected since when the data were plotted there was a slight increase in the difference as the sample interval increased. Therefore, an independent test for the homogeneity of the variance of the data by sample interval was made. Cochran's(5) test was used to determine if the hypothesis of equality of variances was valid.

When a normal probability plot is made, if the data are normally distributed, the plot will resemble a straight line. However, some data points will fall outside the straight line. These points should be tested to determine if they are outliers and deleted if they are.

If the errors are normally distributed with mean equal zero and constant variance, then the standardized residuals should be approximately normal with mean zero and unit variance. A residual larger than 3 or 4 standard deviations from zero is a potential outlier.(5) Using the formula

$$d_{ij} = e_{ij} / \sqrt{MSE}$$

Where: d_{ij} = Standardized Residual

e_{ij} = Residual

MSE = Mean Square Error,

all data points which were potential outliers were tested and deleted if the standardized residual was three or larger.

The purpose of the statistical analysis was to determine if the estimated stopped-time delay was more accurately estimated by using a particular study sample interval, i.e., 5,6,7,..., 30 seconds. Therefore, the hypothesis for this analysis is that all study sample intervals produce the same accuracy in predicting the stopped-time delay and that the intersections have no effect on the results.

The ANOVA indicates that both main factors, i.e., the study interval and the sample (intersection/film number) are not significant. The hypothesis that all sample intervals produce results that are statistically equal and that the intersection does not affect the results, at the 0.01 level of significance, cannot be rejected. Therefore, 99 percent of the time the results will be valid. From this analysis we can conclude that there is statistically no "best" sample interval.

Since there is no statistical difference when a 13-second or a 15-second interval is used we can also conclude that the requirement to use a 13-second interval when the signal cycle is an even multiple of 15 seconds or when the signal is operated in a system is not necessary.

A possible explanation why this result was found may be due to a combination of factors. Vehicle volumes and arrival rates are not constant. Also the start-up delay varies from 3.8 seconds for the first vehicle to 2.1 seconds for the sixth vehicle in the queue.(7) Even during most off-peak periods there will be some back-up, i.e., a queue, at most signalized intersections. Thus, under these varying conditions the point sample will not normally be taken at the same point each time. Therefore, the point sample is not biased.

Reilly, et. al., found that an interval of 13 seconds was a practical lower limit because an observer cannot accurately observe and record the count under peak traffic conditions when a shorter interval is used.(8)

On the basis of this research and the findings of Reilly, et. al., a "best" sample interval can be recommended.

Conclusions and Recommendations

From the statistical analysis it is concluded that there is statistically no difference in the estimated stopped-time delay values produced regardless of the study sample interval used. It is also concluded that it is not necessary to use a 13-second sample interval when the signal cycle is an even multiple of 15 seconds or operated in a system mode. However, Reilly, et. al., found that an interval of 13 seconds is the practical lower limit for conducting stopped-time delay studies. Therefore, it is concluded that a sample interval for conducting field delay studies should not be less than 13 seconds. When a 13-second interval is used an interval timer must be used to give an audible sound to identify when a point sample is to be taken. Since point samples are taken at 0, 15, 30, and 45 seconds when a 15-second sample interval is used it is also concluded that a stopped-time delay study can be made using only a stopwatch using a 15-second interval. Based on these conclusions, the following recommendations are made:

1. A 15-second sample interval should be used when making field delay studies under all signal modes and cycle lengths.

2. When conducting delay studies using time-lapse photography a sample interval as small as 5 seconds may be used to produce slightly more accurate results.
3. Using a 15-second sample interval analyze the study period to determine the optimum length of time a delay study should be conducted at a signalized intersection.

The second phase of the data analysis was to investigate the optimum length of the study period for conducting stopped-time delay studies at signalized intersections.

Notes

(1)Reilly, W.R., C. C. Gardner, and J. H. Kell A Technique for Measurement of Delay at Intersections, Vol. 3, User's Manual, Report No. FHWA-RD-76-137 (Washington D.C.: Federal Highway Administration, Sept. 1976), pp.6-16.

(2)Ibid., p. 6.

(3)Montgomery, Douglas C. Design and Analysis of Experiments 2nd Ed. (New York: John Wiley & Sons, 1984), p. 212.

(4)Ibid., p. 85.

(5)Walpole, Ronald E. and Raymond H. Myers Probability and Statistics for Engineers and Scientists, 2nd Ed. (New York: MacMillan Publishing Co., Inc. 1978), p. 377.

(6)Opcit., p. 89.

(7)Matson, Theodore M., W.S. Smith, and F.W. Hurd. Traffic Engineering (New York: McGraw-Hill Book Co. Inc., 1955) p. 330.

(8)Reilly, et. al., Vol. 1, p. 67.

CHAPTER V

ANALYSIS OF THE STUDY PERIOD USED TO CONDUCT STOPPED-TIME DELAY STUDIES

Introduction

Reilly, et. al., recommended "a minimum of 60 point samples... be taken for each study. This represents a 15- or 13-minute period, depending on the interval between samples used."(1)

Since the length of the study period is directly related to the cost of conducting the study it is desired to use the minimum study period possible. However, the accuracy of the estimated stopped-time delay may also be affected by the length of the study period. Therefore, it is desired to determine the "best" study period which will give the optimum results in terms of the cost of conducting delay studies and the accuracy of the estimated delay.

One of the recommendations in Chapter IV is to use a 15-second sample interval under all signal operating conditions. Therefore, the analysis of the study period was done with a 15-second sample interval.

A FORTRAN computer program was used to analyze the data to compare the estimated delay to the actual delay for study periods of 300 seconds (5 minutes) to 2700 seconds (45 minutes). Using the data produced by the computer program a statistical analysis was made to determine the "best" study period. On the basis of this statistical analysis conclusions were drawn and recommendations were made.

As in the case of determining the "best" sample interval the first activity in analyzing the data was the development of a computer program to compare the estimated stopped-time delay to the actual stopped-time delay.

Development of the Computer Program

The FORTRAN computer program used in analyzing the sample interval was modified to provide the capability of analyzing study periods ranging from 300 seconds (5 minutes) to 2700 seconds (45 minutes).

Since a fixed 15-second sample interval was to be used, the first modification to the program was the deletion of the terminal query to input the starting interval, the ending interval, and the increment. However, since it was desired to evaluate the accuracy of the estimated stopped-time delay through a range of study periods from 300 to 2700 seconds it was necessary to include this feature in the computer program. The program was modified so that the terminal could query the user to input the starting period, the ending period, and the increment.

The analysis of the sample interval involved a comparison of all the data for each sample interval. However, the analysis of the study period required that a comparison of the data be performed in chronological order, i.e., the vehicles that arrived at the approach study section during the first 5 minutes, the first 10 minutes, etc. The computer program was modified to sort all of the data records to put them in chronological order.

Next, a means of identifying the end of each study period had to be incorporated into the computer program. This was accomplished by using a reference value or period which was determined by the length of the study period in seconds multiplied by the filming rate in frames per second. This gave a reference value in frames which was then compared to the Leave Section Frame Number (LSFN) value. If the LSFN value is equal to or greater than the period value, the end of the study period has been reached since all data records are in chronological order.

Since the LSFN value may be slightly larger than the reference period value, the actual study period may be slightly larger than the stated study period. For this reason the study period is identified as a Nominal Study Period in all data summaries.

The reference period value is incremented through the range of study periods in 300 second increments until the maximum study period 2700 seconds (45 minutes) has been reached.

The method of determining the estimated stopped-time delay and the actual observed stopped-time delay is the same as that described in Chapter IV.

The following is a description of the output produced by the FORTRAN program used to perform the data analysis of the study period.

Computer Program Output

The computer program output was divided into five sections. Segment information, division information, data information, duplicate vehicle numbers, and the output data for the study approach for each study period.

The output information is as described in Chapter III except as discussed below.

The Division Header Information and Data Header Information is repeated at the start of the data listing for each lane and at the start of the data listing for each part, i.e., each 49 minute, 30 second filming segment is divided into three parts, A, B, and C, each representing 16 minutes, 30 seconds of real-time.

Next, the duplicate vehicle numbers were identified and listed:

> Duplicate Veh Nos. (two records with the same vehicle number)

Next the following information for the approach study section is listed, for each study period:

Film No.: 1, 2, ..., 20
Direction of Travel: NB, SB, EB, or WB
Filming Date
Day of Week
Time of Day Filming Started
Study Approach Street Name
Intersecting Street Name
City Name

State Name

Number of Duplicate Vehicle Numbers

Number of Vehicles in Study Section at Start of Filming

Number of Vehicles in Study Section at End of Filming

Number of Vehicles on Approach

Number of Vehicles Entering Study Section Normally

Number of Vehicles Leaving Study Section Normally

Number of Vehicles Entering Extraneously

Number of Vehicles Leaving Extraneously

Number of Vehicles Not Stopping

Number of Vehicles Stopping

Number of Vehicles Observed in Study Sample

Study Sample Interval Used: 15 seconds

Estimated Total Stopped-Time Delay

Estimated Average Delay Per Stopped Vehicle

Estimated Average Delay Per Approach Vehicle

Observed Total Stopped-Time Delay

Observed Average Delay Per Stopped Vehicle

Observed Average Delay Per Approach Vehicle

Study Period: 300 seconds, 600 seconds, ..., 2700 seconds

Next, the output data were summarized and analyzed.

Output Data and Analysis

The analysis of the sample interval was based on the value of the difference in seconds between the estimated stopped-time delay per stopped vehicle and the actual observed stopped-time delay per stopped vehicle and the difference per approach vehicle. This statistic was also used in the analysis of the study period.

Table 10 contains the summary results of subtracting the actual delay per stopped vehicle from the estimated delay per stopped vehicle for the peak period data. The unadjusted mean value of the difference varies from a high of -0.407 seconds for a study period of 300 seconds to a low of -0.004 seconds for a study period of 2100 seconds.

Table 11 contains the summary results of subtracting the actual delay per stopped vehicle from the estimated delay per stopped vehicle for the off-peak period data. The unadjusted mean value of the difference varies from a high of -0.778 seconds for a study period of 300 seconds to a low of 0.000 for a study period of 900 seconds.

Table 12 contains the summary results of combining the data for the peak and off-peak periods. The mean value of the combined data varies from a high of -0.593 seconds for a study period of 300 seconds to a low of 0.001 seconds for a study period of 1500 seconds.

The unadjusted data contained in Tables 10, 11, and 12 indicate, by inspection, that the sample standard deviation, S, decreases in value as the study period increases from 300 to 1800 seconds and then it remains constant or increases

NOMINAL STUDY PERIOD SECONDS	$\bar{X}$	S	S^2	χ^2	MEAN SAMPLE SIZE	95% CONF % ERROR	90% CONF % ERROR
300	(-0.070) -0.407	(0.629) 1.238	(0.396) 1.532	(0.223) 0.865	58.4	(16.13) 31.75	(13.54) 26.65
600	(0.077) -0.272	(0.484) 1.204	(0.235) 1.450	(0.089) 0.941	126.6	(8.43) 20.97	(7.08) 17.60
900	0.086	0.728	0.530	0.228	203.7	10.00	8.39
1200	0.046	0.458	0.210	0.081	298.0	5.20	4.36
1500	0.033	0.439	0.193	0.080	387.7	4.37	3.67
1800	0.098	0.368	0.135	0.065	489.3	3.26	2.74
2100	-0.004	0.422	0.178	0.081	573.8	3.45	2.90
2400	0.033	0.521	0.272	0.131	654.7	3.99	3.35
2700	0.010	0.505	0.255	0.124	729.1	3.67	3.08

Table 10. Analysis of Study Period - Estimated Minus Actual Average Delay Per Stopped Vehicle in Seconds For a 15-Second Sample Interval - Peak Period Data

*( ) Expected value, observed value found to be a potential outlier.

NOMINAL STUDY PERIOD SECONDS	$\bar{X}$	S	S^2	X^2	MEAN SAMPLE SIZE	95% CONF % ERROR	90% CONF % ERROR
300	(-0.031) -0.778	(0.830) 1.780	(0.689) 3.168	2.456	35.7	(22.6) 58.4	(19.0) 49.0
600	-0.228	1.204	1.449	0.925	77.6	26.8	22.5
900	0.000	0.968	0.937	0.597	123.3	17.1	14.3
1200	0.075	0.915	0.838	0.495	168.5	13.8	11.6
1500	-0.031	0.725	0.526	0.329	209.5	9.8	8.2
1800	-0.091	0.703	0.495	0.322	254.9	8.6	7.2
2100	-0.184	0.754	0.569	0.387	302.7	8.5	7.1
2400	-0.163	0.857	0.734	0.480	351.0	9.0	7.5
2700	-0.161	0.923	0.852	0.566	400.9	9.0	7.6

Table 11. Analysis of Study Period - Estimated Minus Actual Average Delay Per Stopped Vehicle in Seconds For a 15-Second Sample Interval - Off-Peak Period Data

NOMINAL STUDY PERIOD SECONDS	$\bar{X}$	S	S^2	X^2	MEAN SAMPLE SIZE	95% CONF % ERROR	90% CONF % ERROR
	(-0.051)	(0.707)	(0.514)			(20.50)	(17.20)
300	-0.593	1.504	2.262	3.320	47.05	43.0	36.07
	(0.074)	(0.726)	(0.527)			(14.08)	(11.82)
600	-0.209	1.181	1.394	1.866	102.10	22.9	19.23
	(0.153)	(0.652)	(0.426)			(10.00)	(8.39)
900	0.042	0.836	0.698	0.825	163.50	12.8	10.76
	(0.154)	(0.550)	(0.303)			(7.06)	(5.93)
1200	0.061	0.704	0.496	0.576	233.25	9.0	7.58
	(0.091)	(0.405)	(0.164)			(4.59)	(3.86)
1500	0.001	0.584	0.341	0.409	298.60	6.6	5.56
	(0.096)	(0.344)	(0.118)			(3.49)	(2.93)
1800	0.004	0.555	0.308	0.390	372.10	5.6	4.73
	(0.010)	(0.356)	(0.126)			(3.33)	(2.79)
2100	0.094	0.602	0.362	0.468	438.25	5.6	4.73
	(0.042)	(0.484)	(0.235)			(4.23)	(3.55)
2400	-0.065	0.697	0.486	0.611	502.85	6.1	5.11
	(0.038)	(0.496)	(0.246)			(4.09)	(3.43)
2700	-0.076	0.729	0.532	0.690	565.00	6.0	5.05

Table 12. Analysis of Study Period- Estimated Minus Actual Delay Per Stopped Vehicle in Seconds For a 15-Second Sample Interval - All Data

slightly from 2100 to 2700 seconds. Since the standard deviation measures the dispersion of the data from the mean value it can be inferred that the value of the difference decreases as the study period increases from 300 to 1800 seconds, but a further increase in the study period does not improve the accuracy of the estimated delay.

A linear regression analysis of the standard deviation (dependent variable) vs the study period length (from 300 to 1800 seconds) indicates a high correlation. R values of -0.9406952, -0.9143804, and -0.9492185 for the unadjusted peak period data, the off-peak period data, and the combined data respectively, were found. Therefore, between 80 and 90 percent of the variance in the standard deviation of the difference in delay can be accounted for by the difference in the length of the study period between 300 and 1800 seconds. The linear regression plots are in Appendix I.

Inspection of Table 13, Analysis of Study Period - Estimated Minus Actual Average Delay per Approach Vehicle in Seconds For A 15-Second Sample Interval-Peak Period Data, reveals that the difference in delay values have a range of 0.00 to 0.83 seconds. The mean value of these data have a range of -0.006 seconds with a study period of 2700 seconds to 0.171 seconds with a study period of 900 seconds. The standard deviation of the difference in delay values generally decreases as the sample size increases from 300 to 2100 seconds then slightly increases. A linear regression analysis of the standard deviation, (dependent variable) vs.

NOMINAL STUDY PERIOD SECONDS	$\bar{X}$	S	S^2	X^2	MEAN SAMPLE SIZE	95% CONF % ERROR	90% CONF % ERROR
300	-0.081	0.257	0.066	0.124	125.5	4.5	3.77
600	0.084 (0.098)	0.293 (0.220)	0.086 (0.048)	0.134	248.0	3.6 (2.21)	3.06 (1.85)
900	0.171	0.319	0.102	0.079	381.9	3.2	2.69
1200	0.073	0.212	0.045	0.027	536.3	1.8	1.51
1500	0.074	0.165	0.027	0.021	669.2	1.3	1.05
1800	0.047	0.184	0.034	0.024	803.6	1.3	1.07
2100	0.013	0.167	0.028	0.022	952.6	1.1	0.89
2400	0.013	0.186	0.035	0.031	1061.9	1.1	0.94
2700	-0.006	0.198	0.039	0.029	1174.5	1.1	0.95

Table 13. Analysis of Study Period - Estimated Minus Actual Average Delay Per Approach Vehicle in Seconds For a 15-Second Sample Interval - Peak Period Data

the study period between 300 and 1800 seconds indicates a moderate correlation with a value of R = -0.7448511. The R value increases to 0.7960532 when when the study period is increased to 2100 seconds.

Inspection of Table 14, Analysis of Study Period - Estimated Minus Actual Average Delay Per Approach Vehicle in Seconds For A 15-Second Sample Interval-Off-Peak Period Data, reveals that the difference in delay values have a range of 0.00 to -0.86 seconds. The standard deviation generally decreases as the study period increases from 300 to 1800 seconds then increases slightly and remains constant. A regression analysis of the standard deviation, (dependent variable) vs. the study period from 300 seconds to 1800 seconds indicates a high correlation with a value of R= -0.9672855.

Inspection of the combined data, Table 15, indicates that the standard deviation of the difference in the delay values generally decreases as the study period increases from 300 seconds to 1800 seconds and then increases slightly and remains constant. A linear regression analysis of the standard deviation, (dependent variable) vs the study period from 300 to 1800 seconds indicates a high correlation with a value of R= -0.9513819. Typical linear regression plots are in Appendix F.

Based on this analysis it appears that there is a correlation between the standard deviation of the difference in delay values and the length of the study period, for

NOMINAL STUDY PERIOD SECONDS	$\bar{X}$	S	S^2	X^2	MEAN SAMPLE SIZE	95% CONF % ERROR	90% CONF % ERROR
300	-0.063	0.504	0.254	0.371	84.1	10.8	9.0
600	-0.015	0.532	0.283	0.260	161.7	8.2	6.9
900	0.019	0.369	0.136	0.141	242.0	4.6	3.9
1200	0.049	0.324	0.105	0.113	331.9	3.5	2.9
1500	0.031	0.224	0.050	0.069	406.1	2.2	1.8
1800	-0.006	0.177	0.031	0.062	486.6	1.6	1.3
2100	-0.042	0.209	0.044	0.077	577.0	1.7	1.4
2400	-0.044	0.244	0.059	0.102	659.3	1.9	1.6
2700	-0.056	0.246	0.060	0.115	746.9	1.8	1.5

Table 14. Analysis of Study Period - Estimated Minus Actual Average Delay Per Approach Vehicle in Seconds For a 15-Second Sample Interval - Off-Peak Period Data

NOMINAL STUDY PERIOD SECONDS	$\bar{X}$	S	S^2	X^2	MEAN SAMPLE SIZE	95% CONF % ERROR	90% CONF % ERROR
300	-0.068	0.388	0.151	0.495	104.80	7.4	6.23
600	0.035 (0.058)	0.421 (0.298)	0.178 (0.089)	0.394	204.85	5.8 (3.3)	4.84 (2.78)
900	0.095	0.345	0.119	0.220	311.95	3.8	3.21
1200	0.061	0.267	0.071	0.140	434.10	2.5	2.11
1500	0.053	0.193	0.037	0.090	537.65	1.6	1.37
1800	0.021	0.178	0.032	0.086	645.10	1.4	1.15
2100	-0.015	0.186	0.035	0.099	764.80	1.3	1.11
2400	-0.016	0.213	0.045	0.133	860.60	1.4	1.19
2700	-0.032	0.218	0.048	0.144	960.70	1.4	1.16

Table 15. Analysis of Study Period - Estimated Minus Actual Average Delay Per Approach Vehicle in Seconds For a 15-Second Sample Interval - All Data

study periods of 300 seconds to 1800 seconds. This suggests a possible relationship between the accuracy of the estimated delay and the study sample size. Thus, a linear regression analysis of the standard deviation (dependent variable) vs the mean sample size was conducted.

The results of this analysis indicate a moderate to high correlation between the standard deviation and the mean sample size. However, the correlation decreases as the length of the study period increases to 2700 seconds. This suggests that there may be an optimum length of study period beyond which the accuracy does not improve.

A summary of the number of vehicles stopping during the study period for each observation can be found in Table 16. Table 17, contains a summary of the number of vehicles on the study section approach during the study period for each observation.

To determine if there is a statistically "best" study period a statistical analysis of the study period was necessary.

Statistical Analysis

As in the analysis of the sample interval the statistic to test is the value of the difference between the estimated stopped-time delay and the actual observed stopped-time delay for the range of study periods used for each of the study intersections, using a 15-second sample interval.

Since only one observation was made at each intersection, the analysis must be made without replication.

NOMINAL STUDY PERIOD SECONDS	$\overline{X}$(ALL)	S(ALL)	$\overline{X}$(PEAK)	S(PEAK)
300	47.05	32.42	58.4	37.80
600	102.10	68.19	126.6	77.01
900	163.50	109.08	203.7	124.59
1200	233.25	164.43	298.0	190.46
1500	298.60	208.89	387.7	240.73
1800	372.10	258.05	489.3	295.80
2100	438.25	303.49	573.8	346.67
2400	502.85	333.73	654.7	375.58
2700	565.00	364.26	729.1	404.46

Table 16. Analysis of Study Period - Number of Vehicles Stopping During Study Period.

NOMINAL STUDY PERIOD SECONDS	$\bar{X}$(ALL)	S(ALL)	$\bar{X}$(PEAK)	S(PEAK)
300	104.80	47.80	125.5	56.83
600	204.85	89.54	248.0	102.19
900	311.95	133.48	381.9	151.11
1200	434.10	188.29	536.3	206.03
1500	537.65	230.73	669.2	248.72
1800	645.10	273.48	803.6	294.67
2100	764.80	323.80	952.6	345.70
2400	860.60	350.58	1061.9	372.55
2700	960.70	375.38	1174.5	396.32

Table 17. Analysis of Study Period - Number of Vehicles On Study Approach During Study Period

There are problems associated with conducting an ANOVA without replication.The error variance is not estimable; that is, the two-factor interaction effect and the experimental error cannot be separated. Consequently, there are no tests on the main effects unless the interaction effect is zero. However, a two-factor factorial ANOVA was conducted using the SAS Procedure GLM.

The two factors analyzed were the study period and the sample (intersection/film number). The hypothesis for this analysis is that all study periods produce the same accuracy in predicting the stopped-time delay and that the intersections have no effect on the results.

The results of the ANOVA was that the sample, i.e., the intersection/film number, is statistically significant. Also, in some individual analysis the Tukey test was significant indicating interaction between the study period and the sample (intersection/film number). Since the previous analysis of the sample interval did not indicate that the intersections were statistically significant, these results were not expected.

Recognizing that the results of any ANOVA are of questionable status, if, in fact, the intersection has an effect on the results; a one-way ANOVA of the study period was conducted for each set of data and the results indicate that the study period is not significant. Therefore, if the intersections have no effect on the results, we cannot reject the hypothesis that the study periods produce results that are statistically equal at the 0.01 level of significance. However, since the results are clouded by the fact that the intersections may have an effect on the results, another method of analyzing the data was needed.

The method chosen to analyze the study period was the Chi-Square Goodness of Fit Test. Using the formula⁽²⁾

$$X^2 = \frac{\sum_{i=1}^{k} (O - e)^2}{e}$$

Where: X^2 = Chi-square

O = Estimated delay

e = Actual Observed delay

The Chi-square value for each study period was calculated for each set of data, i.e., Table 10, 11, 12, 13, 14, and 15. The resulting statistic was found not to be significant for all study periods at the 0.01 level of significance. Therefore, it can be concluded that 99 percent of the time the estimated delay value will be correct for a given study period. Also, this analysis supports the one-way ANOVA results that there is no statistical difference in the study periods. The earlier analysis of the data indicate that the quality of the estimated delay value may be affected by the sample size. Therefore, the expected error was calculated at the 95 percent and 90 percent confidence level for each study period using the formula⁽³⁾

$$e = \frac{Z\ alpha/2\ S\ (100)}{n}$$

Where: e = % Error

Z alpha/2 = 1.96 (95% Conf)

= 1.645 (90% Conf)

n = mean sample size

S = sample standard deviation

The results of these calculations can be found in Tables 10, 11, 12, 13, 14 and 15. The magnitude of the expected error has a range of 58.4% (95% Confidence level) for a 300-second study period with a mean sample size of 35.7 vehicles to 1.1% (95% Confidence level) for 2100-second study period with a mean sample size of 952.6 vehicles.

When the one-way ANOVA was conducted, the data points which did not fall on the normal probability line were tested for potential outliers. The values which were determined to be potential outliers were replaced with the expected value which was calculated by the SAS Procedure GLM. Using these adjusted data a new mean value of the difference in delay was calculated, a new standard deviation, a new variance, and a new percent error was also calculated. If these potential outliers are, in fact, outliers, the results are significantly improved by using the expected values. These results can also be found in Tables 10, 11, 12, 13, 14, and 15.

The statistical analysis thus far has suggested that there is a relationship between the accuracy of the estimated stopped-time delay value and the size of the sample which exists during the study period. Therefore, further study of this relationship, vis-a-vis a minimum sample size, was undertaken.

Since the standard deviation measures the dispersion of the data from the mean value, i.e., a measure of the consistency of the data or the quality of the data, this statistic was analyzed against the mean sample size for each individual study period. A linear regression analysis was performed on the unadjusted data, with the standard deviation being the dependent variable. Each study period, i.e., 300 seconds, 600 seconds, ..., 2700 seconds, was analyzed independently. The results of this analysis are in Table 18, Analysis of Study Period-Recommended Sample Size For A Specific Study Period.

As can be seen by inspecting Table 18, the linear regression analysis produced a range of correlation coefficients from a high of -0.9647568 for a study period of 300-seconds to a low of -0.8513167 for a study period of 1800-Seconds. Based on this analysis, it was felt that the correlation between the standard deviation and the mean sample size is sufficient to predict a recommended sample size for each study period.

Using the regression equation for each study period, a recommended minimum volume (sample size) was calculated for

STUDY PERIOD	VOLUME	STD DEV	CORRELATION COEFFICIENT	MINIMUM VOLUME	DESIRABLE VOLUME	EST % ERROR FOR MIN VOL 95% CONF	LINEAR REGRESSION EQUATION
300	58.4	1.238	-0.9647568	75	130	21.3	Y=-0.0177668X+2.2942577
	35.7	1.780					
	47.1	1.504					
	125.5	0.257					
	84.1	0.504					
	104.8	0.388					
	129.1	0.000					
	75.9	0.945					
600	126.6	1.204	-0.933576	150	280	12.7	Y=-0.0062942x+1.771884
	77.6	1.204					
	102.1	1.181					
	248.0	0.293					
	161.7	0.532					
	204.9	0.421					
	281.5	0.000					
	153.5	0.806					
900	203.7	0.728	-0.9111557	240	460	7.6	Y=-0.0027X+1.2360512
	123.3	0.969					
	163.5	0.836					
	381.9	0.319					
	242.0	0.369					
	312.0	0.345					
	457.8	0.000					
	237.7	0.594					
1200	298.0	0.458	-0.9131137	335	590	5.2	Y=-0.0018821X+1.1080264
	168.5	0.915					
	233.3	0.704					
	536.3	0.212					
	331.9	0.324					
	434.1	0.267					
	588.7	0.000					
	333.7	0.480					

Table 18. Analysis of Study Period - Recommended Sample Size for a Specific Study Period

1500	387.7	0.439	-0.9013805	420	725	3.7	Y=-0.0012672x+0.9182068
	209.5	0.725					
	298.6	0.584					
	669.2	0.165					
	406.1	0.224					
	537.7	0.193					
	724.6	0.000					
	418.1	0.388					
1800	489.3	0.368	-0.8513167	510	875	3.1	Y=-0.0009843X+0.8614312
	254.9	0.703					
	372.1	0.555					
	803.6	0.184					
	486.6	0.177					
	645.1	0.178					
	875.2	0.000					
	508.6	0.361					
2100	573.8	0.422	-0.8842087	600	1015	3.1	Y=-0.0009409X+0.955968
	302.7	0.754					
	438.3	0.602					
	952.6	0.167					
	577.0	0.209					
	764.8	0.186					
	1016.0	0.000					
	601.5	0.390					
2400	654.7	0.521	-0.8924558	680	1135	3.4	Y=-0.0009991X+1.1341221
	351.0	0.857					
	502.9	0.697					
	1061.9	0.186					
	659.3	0.244					
	860.6	0.213					
	1135.1	0.000					
	681.7	0.453					
2700	729.1	0.505	-0.8947596	765	1240	3.3	Y=-0.0009855X+1.2216377
	400.9	0.923					
	565.0	0.729					
	1174.5	0.198					
	746.9	0.246					
	960.7	0.218					
	1239.6	0.000					
	762.9	0.470					

Table 18. Cont.

the mean of the standard deviations for each study period. A recommended desirable volume (sample size) was calculated by assuming a standard deviation equal to zero. These recommended values are in Table 18.

The expected error (at the 95% confidence level) for the recommended minimum volume was also calculated for each study period. These results are also in Table 18.

Although the statistical analysis did not identify a "best" study period conclusions can still be drawn and certain recommendations made.

Conclusions and Recommendations

Without regard for the length of the study period it can be concluded that the mean value of the difference between the estimated stopped-time delay and the actual observed stopped-time delay is small enough to be insignificant for most traffic engineering purposes. The mean value of the difference in delay has a range of zero to -0.778 seconds. It is also concluded that the estimated stopped-time delay is a good estimate of the actual stopped-time delay based on the Chi-Square Goodness of Fit Test.

Based on an analysis of variance study it can be concluded that there may be factors within each sample (intersection/film number) that can cause the sample to be statistically significant. Based on the regression analysis it is concluded that one factor that may cause the sample to be significant is the size of the vehicle sample which occurs during the study period. It can also be concluded that there is a linear correlation between the standard deviation of the difference between the estimated and actual stopped-time delay and the mean sample size within a given study period. From the expected error analysis it can be concluded that the expected error decreases as the length of the study increases. However, little improvement in the percent error can be expected if the length of the study is increased beyond 25 minutes. Based on these conclusions the following recommendations are made:

1. When conducting a field stopped-time delay study at a signalized intersection the length of the study period be determined by the minimum volume shown in Table 19.
2. When conducting a delay study the length of the study period be based on the level of error that is appropriate for the study being made.
3. The procedure for conducting intersection delay studies be modified to include a minimum volume requirement for the study period selected.

During the course of conducting a research project questions arise which are not answered by the current project. These unanswered questions are potential topics for additional research.

Notes

(1)Reilly, W.R., C.C. Gardner, and J.H. Kell A Technique

STUDY PERIOD MINUTES	MINIMUM VOLUME	DESIRABLE VOLUME	ESTIMATED PERCENT ERROR FOR MIN VOL 95% CONFIDENCE
5	75	130	21
10	150	280	13
15	240	460	8
20	335	590	5
25	420	725	4
30	510	875	3
35	600	1015	3
40	680	1135	3
45	765	1240	3

Table 19. Recommended Sample Size for a Specific Study Period and Estimated Error

for Measurement of Delay at Intersections, Vol. 3, User's Manual, Report No. FHWA-RD-76-137 (Washington, D.C.: Federal Highway Administration, Sept. 1976), p.6.

(2) Walpole, Ronald E. and Raymond H. Myers Probability and Statistics for Engineers and Scientists, 2nd. Ed. (New York: MacMillan Publishing Co., Inc., 1978), p. 266.

(3) Ibid., p. 197.

CHAPTER VI

ADDITIONAL RESEARCH

Introduction

During the conduct of this research project several questions arose which went unanswered. Some of these unanswered questions are worthy of additional research. Therefore, the following topics are recommended for additional research.

Additional Research Recommended

1. The recommendations on the length of the study period, vis-a-vis a minimum sample size, are based on data from ten different intersections located in five states across the United States. However, it would be desirable to verify the accuracy of the volume recommendations through additional research.
2. Replication can provide a means to obtain an estimate of the experimental error which can be used in determining whether observed differences in the data are truly statistically different. Also, replication can provide a sample mean which can be used to estimate more precisely the effect of a study factor. Additional research is recommended to determine the effect replication has on the

accuracy of predicting the true stopped-time delay at signalized intersections.

3. It is generally accepted by traffic engineers that a stopped-time delay of 30 seconds per vehicle or more on an individual approach at an unsignalized intersection may be considered significant. However, stopped-time delay at signalized intersections is a relative value. Additional research is recommended to determine what level of delay is significant at a signalized intersection. Consideration should be given to peak periods, off-peak periods, the size of the community, etc.
4. The intersection delay study procedure developed by Reilly, et.al., recommends that "a peak traffic period and an off-peak period should be studied to give a balanced view of intersection operation."(1) Additional research is recommended to develop a meaningful ratio of peak period delay to the off-peak period delay. Such a ratio could indicate the relative performance of the intersection.
5. There is evidence that the accuracy of the estimate of stopped-time delay is related to the sample size for a particular length of study. If this is verified through the

additional research recommended in 1, above, additional research should also be undertaken to determine if there are other intersection features which affect the accuracy of the estimate of stopped-time delay at signalized intersections.

6. Buehler, et .al.(2) concluded that field sampling of queue backup was much simpler to use than field sampling of stopped-time delay. Assuming this to be a valid conclusion it would be desirable to develop an accurate procedure to estimate delay using queue backup. Such a procedure would be greatly facilitated by using time-lapse photography to measure the queue backup on a selected sample interval, e.g., 10-seconds, 15-seconds, etc. Queue back-up can be measured in terms of length of the queue in feet. This could be facilitated by placing measured marks on the pavement prior to starting a delay study. Therefore, additional research is recommended to determine the feasibility of accurately estimating stopped-time delay by measuring queue back-up.

Notes

(1)Reilly, W.R., C.C. Gardner, and J.K. Kell A Technique for Measurement of Delay At Intersections, Vol. 3, User's

Manual, Report No. FHWA-RD-76-137 (Washington, D.C.: Federal Highway Administration, September 1976), p.6.

(2)Buehler, Martin G., Thomas J. Hicks, Donald S. Berry "Measuring Delay by Sampling Queue Back-up," *Transportation Research Record 615*, 1976, pp. 30-36.

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APPENDIX A
DIAGRAMS OF THE STUDY INTERSECTIONS

LAYOUT OF STUDY INTERSECTION

CITY ARLINGTON STATE MASS

INTERSECTION PLEASANT ST./MASSACHUSETTS AVE. FILM NO'S. 1,2

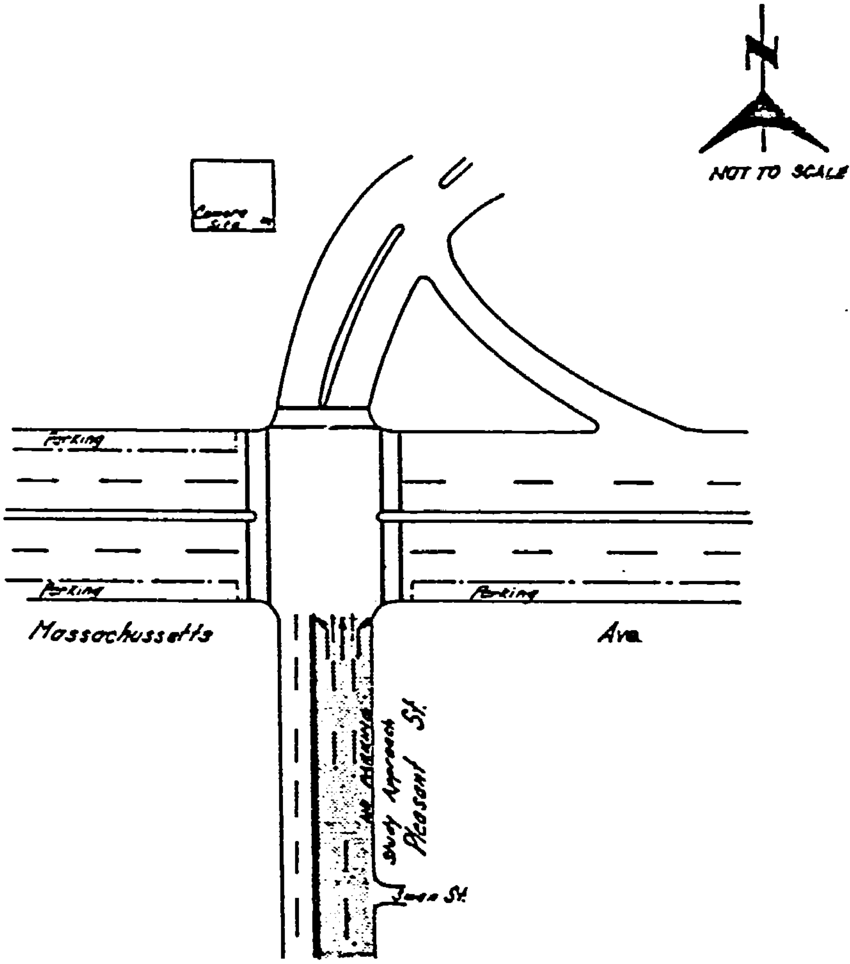


Figure A-1. Study Intersection For Film Nos. 1 and 2

LAYOUT OF STUDY INTERSECTION

CITY CAMBRIDGE STATE MASS

INTERSECTION MASSACHUSETTS AVE./EVERETT ST. FILM NO'S. 3,4

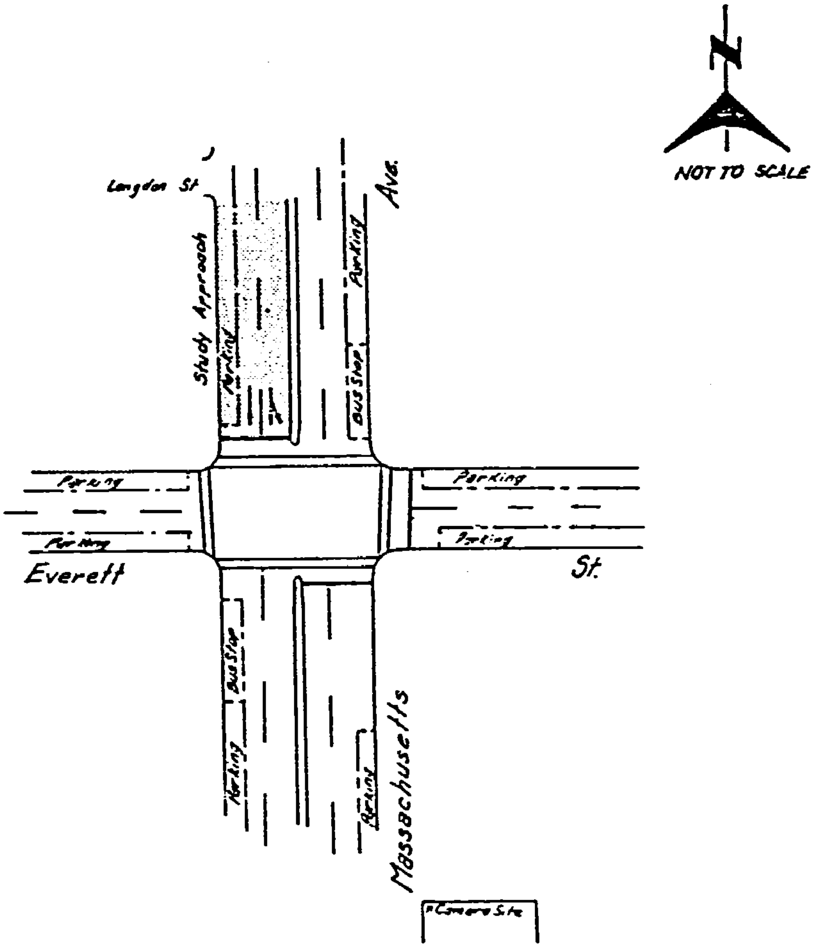
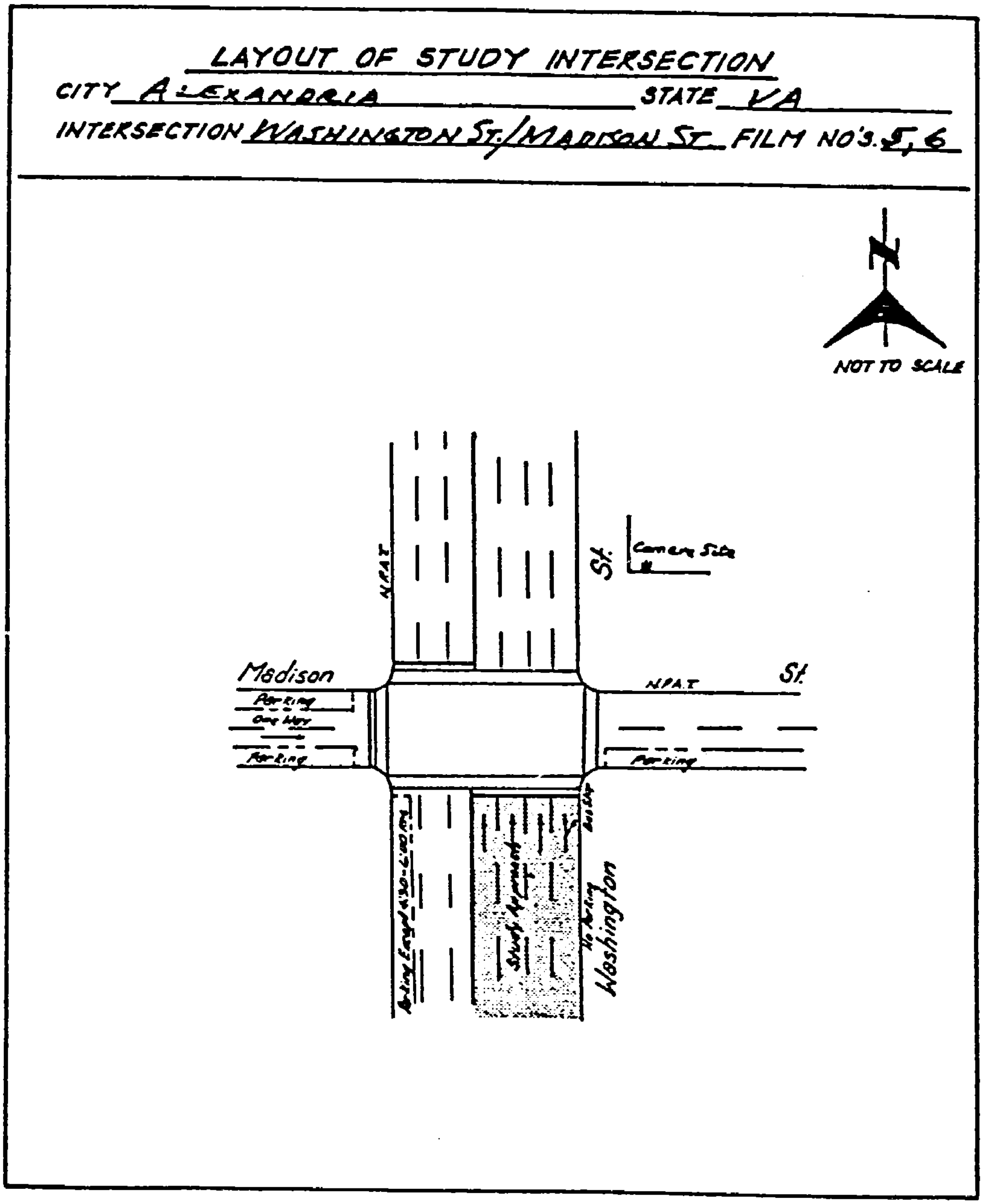


Figure A-2. Study Intersection For Film Nos. 3 and 4



LAYOUT OF STUDY INTERSECTION

CITY ALEXANDRIA STATE VA

INTERSECTION WASHINGTON ST./MADISON ST FILM NO'S. 5, 6

Figure A-3. Study Intersection For Film Nos. 5 and 6

LAYOUT OF STUDY INTERSECTION

CITY FALLS CHURCH STATE VA

INTERSECTION LEESBURG PIKE/HAYCOCK RD FILM NO'S. 7, 8

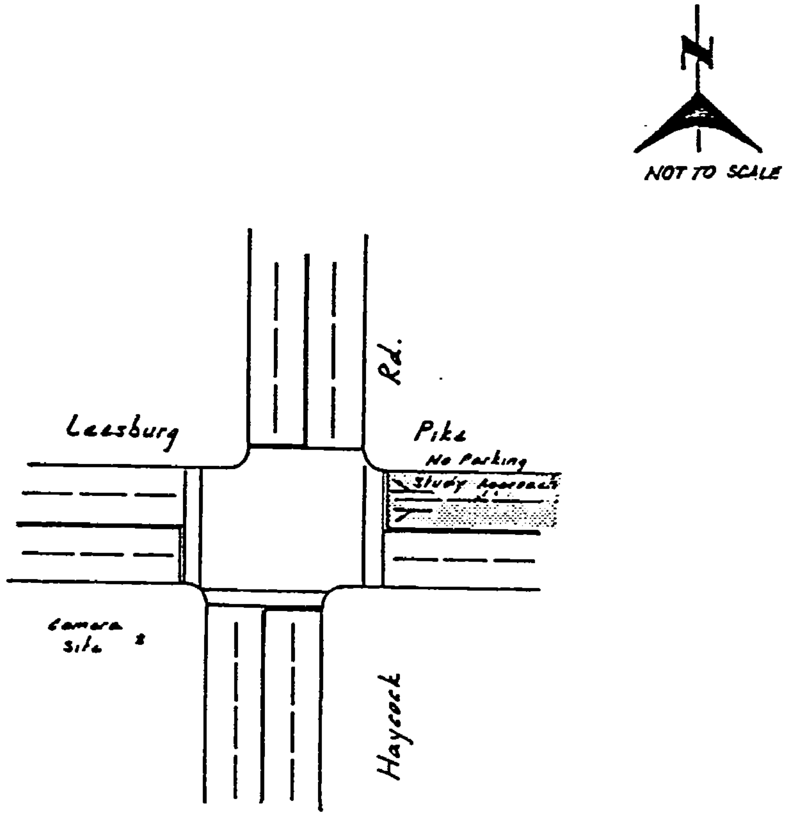


Figure A-4. Study Intersection For Film Nos. 7 and 8

LAYOUT OF STUDY INTERSECTION

CITY Wheaton STATE MD

INTERSECTION University Blvd/Viers Mill Rd FILM NO'S. 9, 10

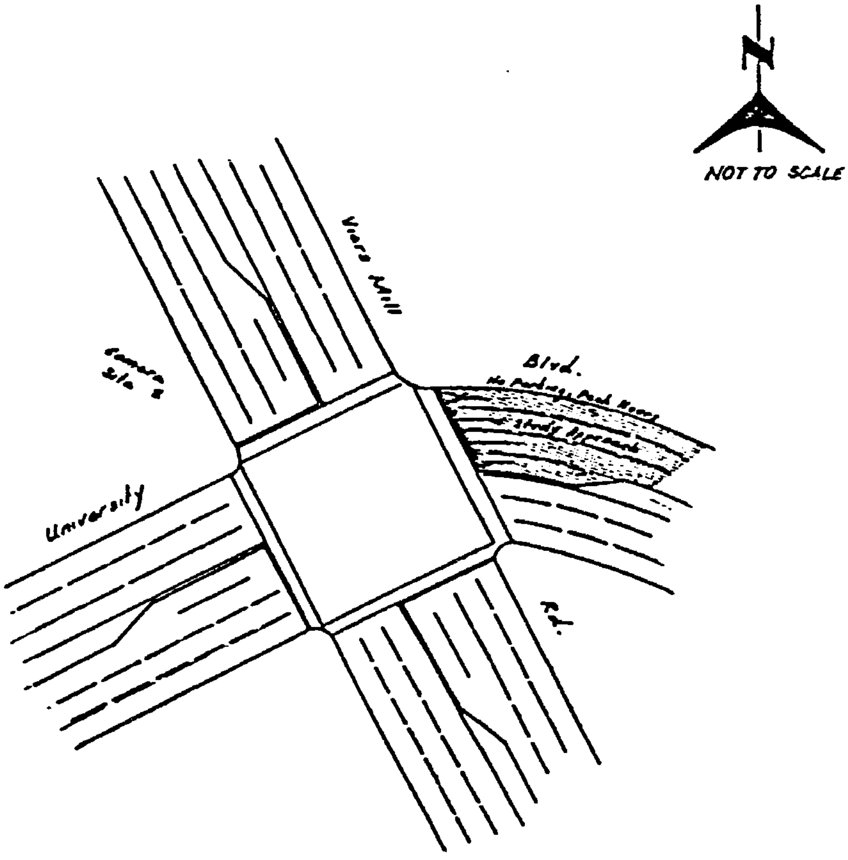


Figure A-5. Study Intersection For Film Nos. 9 and 10

LAYOUT OF STUDY INTERSECTION

CITY OKLAHOMA CITY STATE OK

INTERSECTION CLASSEN BLVD./NW 23rd ST. FILM NO'S. 11, 12

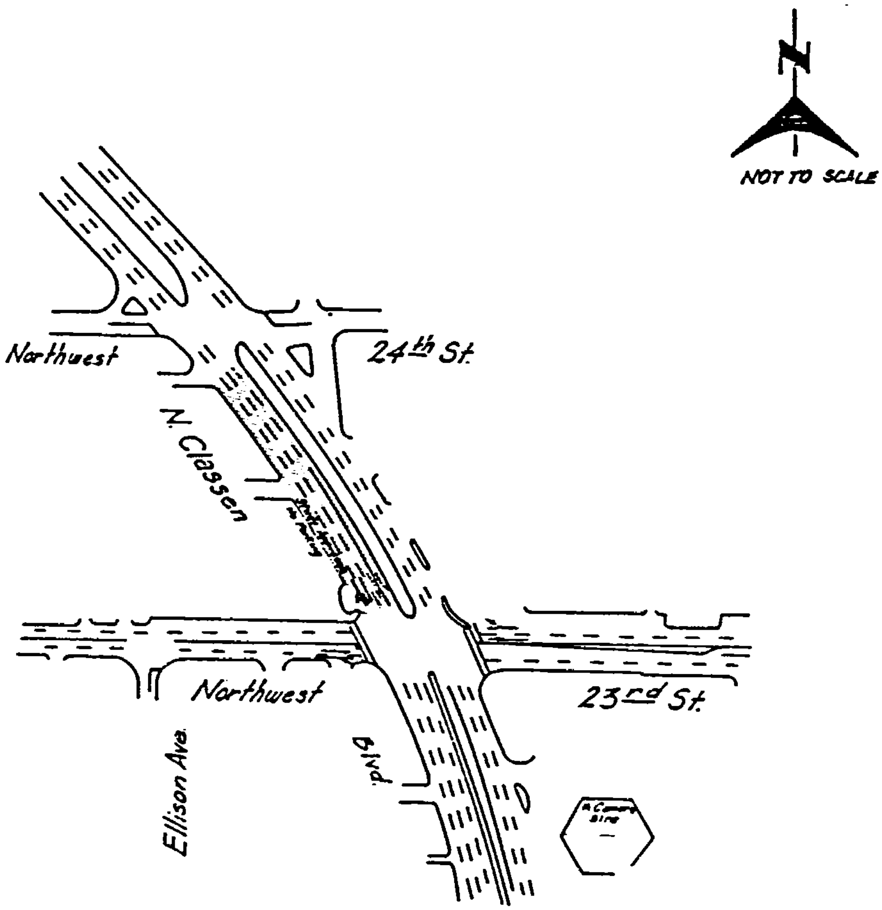


Figure A-6. Study Intersection For Film Nos. 11 and 12

LAYOUT OF STUDY INTERSECTION

CITY Oklahoma City STATE OK

INTERSECTION NW Expressway/Pennsylvania Ave. FILM NO'S. 13, 14

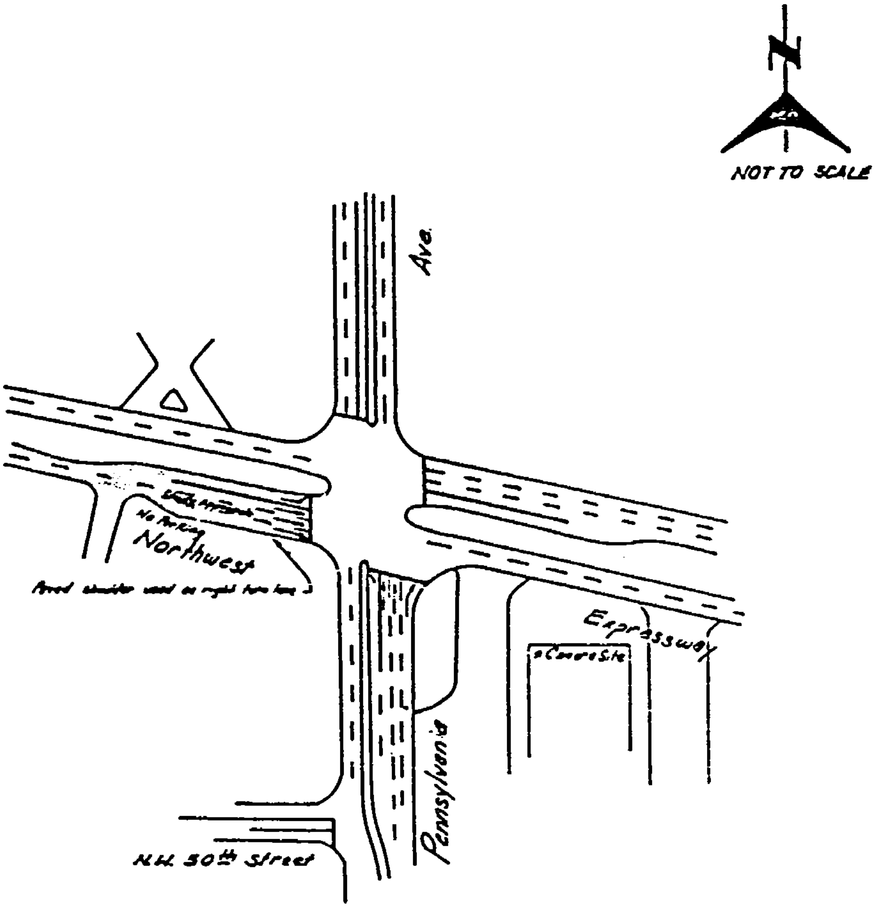


Figure A-7. Study Intersection For Film Nos. 13 and 14

LAYOUT OF STUDY INTERSECTION

CITY TUCSON STATE AZ

INTERSECTION BROADWAY/CRAYCROFT RD. FILM NO'S. 15, 16

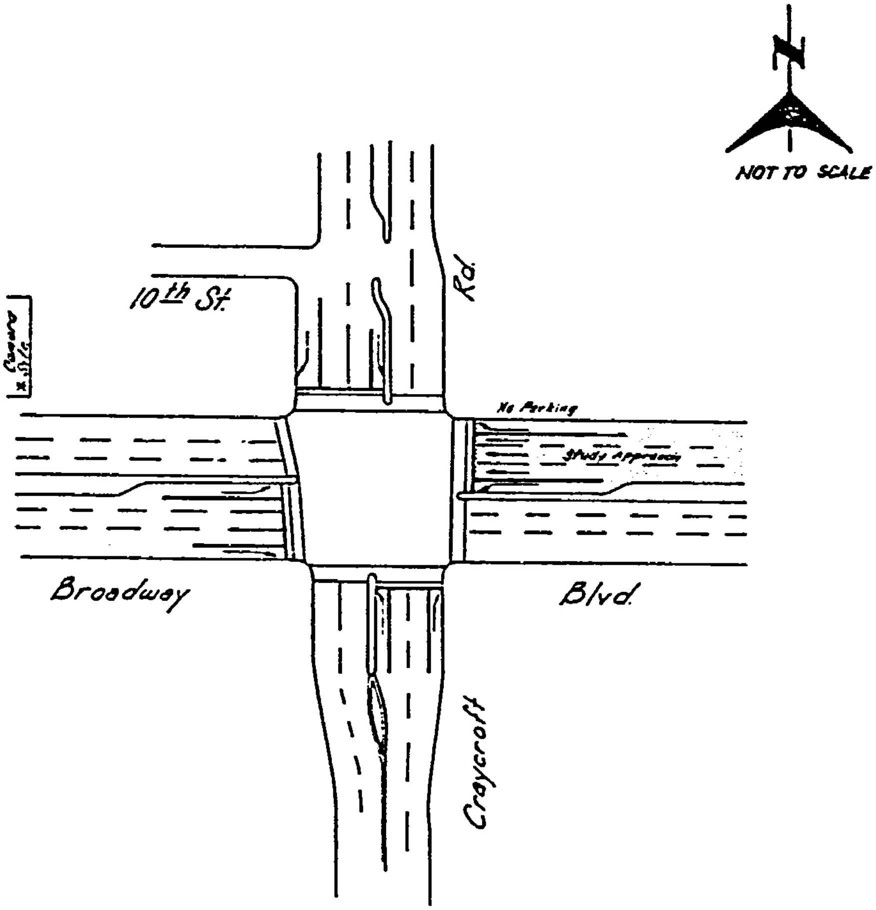


Figure A-8. Study Intersection For Film Nos. 15 and 16

LAYOUT OF STUDY INTERSECTION

CITY TUCSON STATE AZ

INTERSECTION CONGRESS ST./GRANADA AVE. FILM NO'S. 17, 18

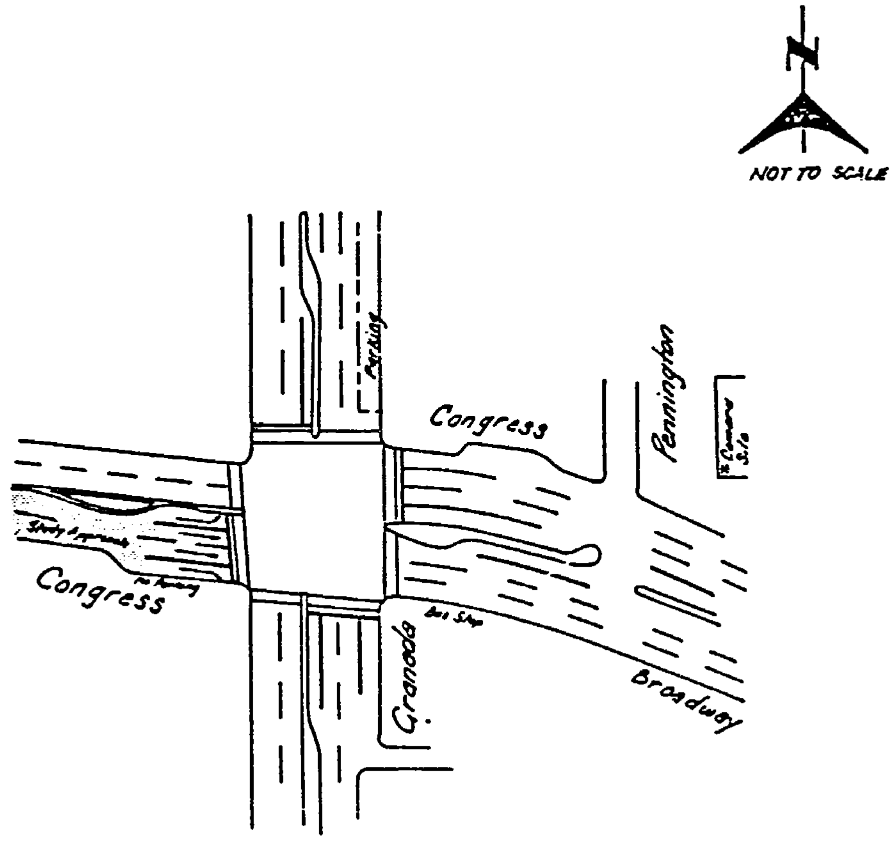


Figure A-9. Study Intersection For Film Nos. 17 and 18

LAYOUT OF STUDY INTERSECTION

CITY TUCSON STATE AZ

INTERSECTION SPEEDWAY BLVD./MOUNTAIN AVE. FILM NO'S. 19, 20

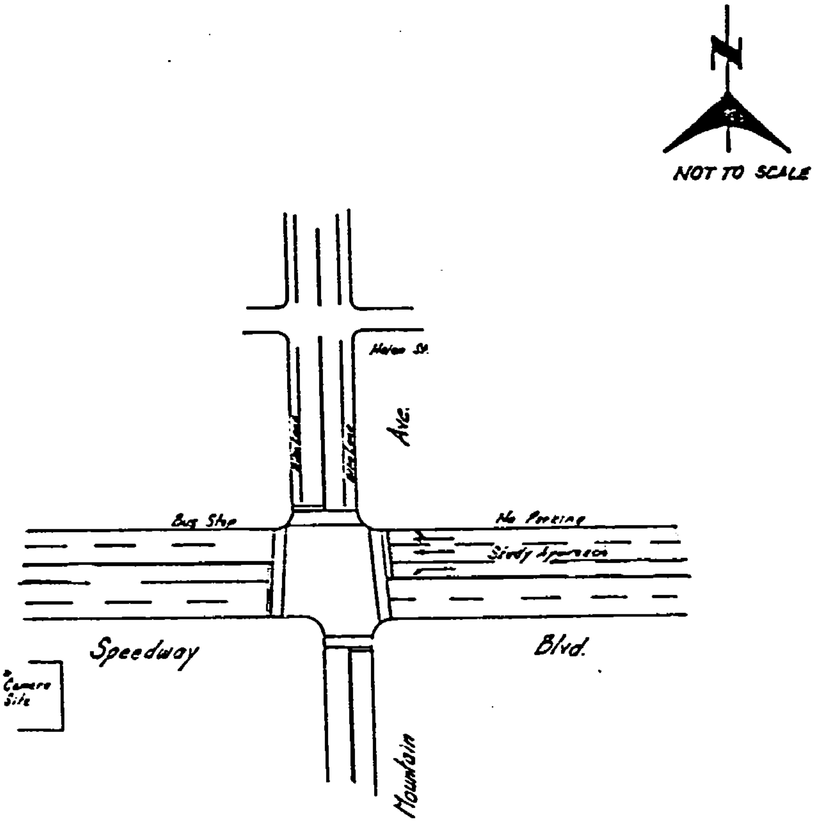


Figure A-10. Study Intersection For Film Nos. 19 and 20

APPENDIX B

INTERSECTION DELAY STUDY PROCEDURE DEVELOPED BY REILLY, ET. AL.

3. INTERSECTION DELAY STUDY

3.1 STUDY OBJECTIVES

The principal objective of the Intersection Delay Study is to collect data on the approach to a signalized intersection such that an accurate estimate of approach delay per vehicle and stopped delay per vehicle can be made. The Percent Stopping Study (see Section 4 for description) must be taken simultaneously with the delay study in order to calculate these two measures of performance on a "per vehicle" basis.

3.2 STUDY REQUIREMENTS

A step-by-step approach should be followed in the design of an Intersection Delay Study. The following elements must be considered.

Select Intersection Approach To Be Studied - if all approaches to a single intersection are to be studied, it is best to do so on the same day to minimize personnel costs. However, it may be difficult to study all approaches under peak conditions if the peak period is relatively short.

Select Time Period To Be Studied - for most applications a peak traffic period and an off-peak period should be studied to give a balanced view of intersection operation.

Select Length of Study Period - a minimum of 60 point samples should be taken for each study. This represents a 15- or 13-minute period, depending on the interval between samples used. If an entire intersection is to be studied, it is recommended that each approach be observed for 60 point samples, with the field crew moving from approach to approach until all have been studied. This procedure can be repeated to obtain an additional 60 point samples on each approach if time permits. It is recommended that lengths of studies be either 60, 90, or 120 point samples. Availability of manpower will be the principal determinant of which length is used.

Determine Type of Traffic Signal Operation - for each study period a determination of the mode of operation of the traffic signal must be made. Modes include pretimed, actuated, and interconnected system control. For each proposed study period, the cycle length of pretimed or the background cycle of system control is determined. If the cycle length cannot be determined in advance of the study, a short investigation is made in the field just prior to performing the work.

Determine Interval Between Samples[4] - if a signal is operating in a pretimed or system mode, use a 13-second interval for cycle lengths of 45, 60, 75, 90, 105, 120, 135, or 150 seconds. For all other cycle lengths in a pretimed or system mode, use a 15-second interval between samples. For all traffic actuated signals not operating in a system, use a 15-second interval.

Determine Means for Obtaining Volume Count - a volume count must be taken simultaneously with the Intersection Delay Study if measures of performance are to be calculated on a "per vehicle" basis. It is recommended that the Percent Stopping Study (see Section 4) be used to obtain this volume count. However, a simple count of total volume using either one observer or some type of mechanical counter could be used in lieu of the Percent Stopping Study.

Select Observation Point - if possible, this should be done prior to the day of the study. Usually the best location is on the right-hand side of the approach, in the shoulder or sidewalk area. However, if the site is hilly, other locations may be better. Exhibit 1 shows possible locations. If inclement weather is probable, the use of a vehicle is recommended and the observation point must accommodate a parked vehicle. If a vehicle is used it must be positioned so as not to be conspicuous or hazardous to traffic using the intersection. Rooftops or buildings offer good locations.

3.3 MANPOWER REQUIREMENTS

Elements related to manpower training and assignments are described below for the Intersection Delay Study. A complete summary of manpower requirements for both the Intersection Delay Study and the Percent Stopping Study is given in Section 5.

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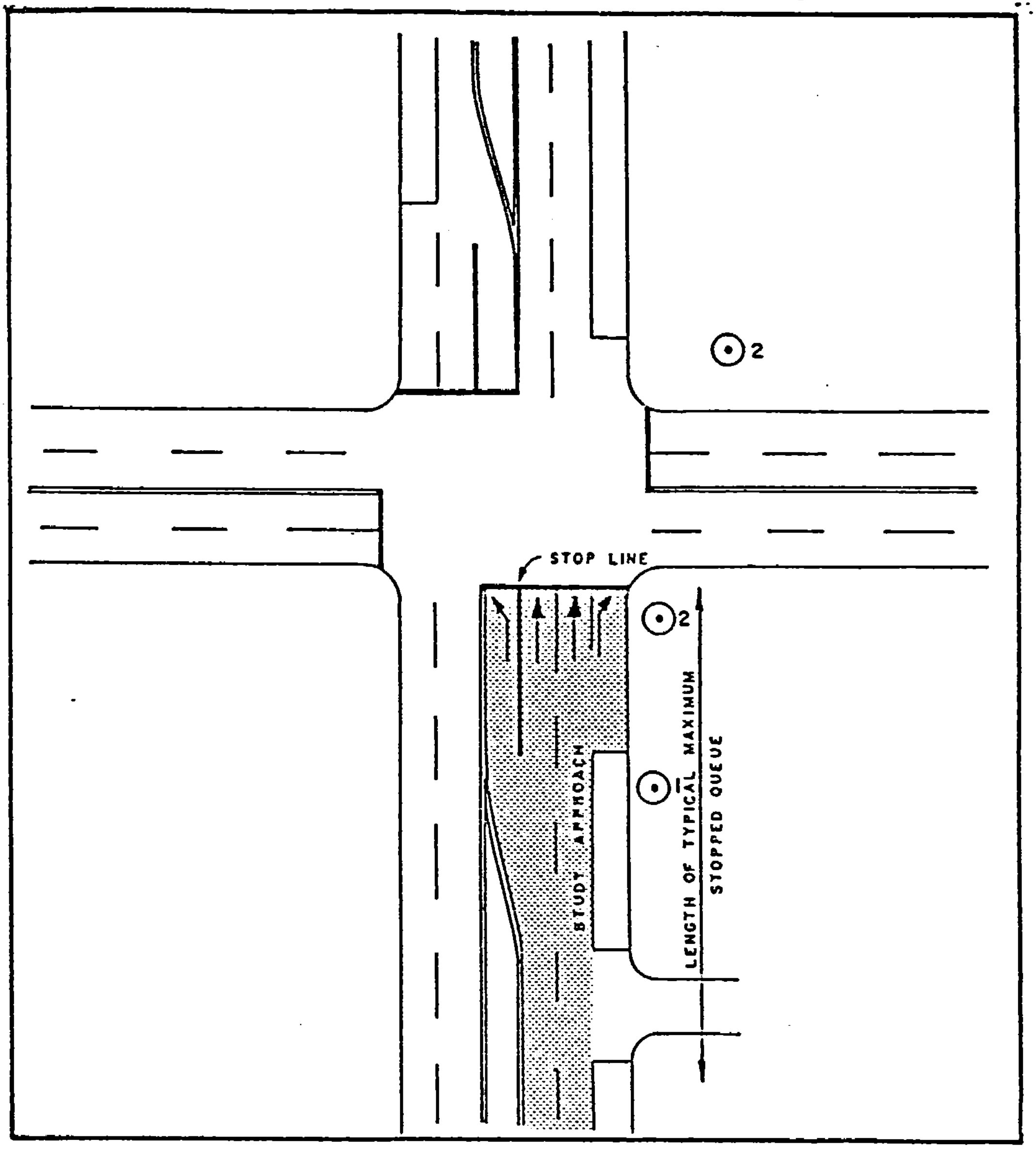
[4] For traffic signals operating on a fixed cycle length, the interval between samples should not be an even divisor of the cycle length. This restriction is not important when the cycle length is greater than 150 seconds.

EXHIBIT 1. LOCATION OF FIELD OBSERVATION POINTS



Legend: 1 = Recommended observation point for Intersection Delay Study, midway along length of average maximum stopped queue to be observed.
2 = Preferred observation points for Percent Stopping Study.

Figure B-1. Location of Field Observation Points

Estimate Manpower Requirements - from local knowledge of flow conditions at the study site, estimate the number of persons needed as follows. Use one person for approaches with one lane, regardless of traffic volume. For two-lane approaches, use one person if most stopped queues do not exceed 25 vehicles, or 500 feet (152 meters) in each lane. For approaches with three or more lanes, use one person if most stopped queues do not exceed 10 vehicles, or 200 feet (61 meters) in each lane. For all other traffic conditions use a two-person team.

If no information on queue length exists, a rough estimate can be made by the following calculation.

$$\text{Average Maximum Queue (in vehicles per lane per cycle)} = \left(\frac{\text{Cycle Length}}{3600}\right)\left(\frac{(.5)\ (\text{Volume Per Hour})}{(\text{No. of Lanes})}\right)$$

Assign Responsibilities - for each Intersection Delay Study a "crew chief" is assigned and is responsible for all aspects of the field work, including the Percent Stopping Study if performed at the same time. For the Intersection Delay Study the crew chief serves as one of the "delay observers." If traffic conditions warrant, a second person is also assigned as a delay observer. The delay study team is thus comprised of the crew chief and one additional delay observer if necessary.

Perform Training - using this manual as a guide, the delay study team should be assembled and trained. A visit to the field for performance of a short pilot study is helpful if the team members are not experienced in performing this type of study.

3.4 EQUIPMENT REQUIREMENTS

The following items will be needed in the performance of an Intersection Delay Study.

Timing Device for Sampling Points (1 per team) - it is recommended that a small battery-powered cassette recorder or other audio device be used to provide an audible cue at each sampling point. The tape should start with the word "begin" to signify the zero point of the study. Then, a cue (the word "now" is suggested) is given at each sampling point. It is recommended that the tape have a total of 120 cues to cover the longest possible study length. Following cue nos. 30, 60, 90, and 120 the number of the sampling point should be given audibly.

It is recommended that the user agency prepare one tape for studies with a 13-second interval between samples and one tape with 15-second intervals. Prior to each field study, it is essential that the power source of the recorder be fully charged and that a check be made of the playback speed and the audible cues to ensure that an accurate time interval will be produced in the field. The most convenient types of recorder are those which either fit into a pocket or which have a strap for suspension from a belt.

If a cassette recorder is not available, a stopwatch with a "fly-back" feature and a sweep of 60 seconds is used. The stopwatch should be calibrated from time to time to ensure accurate results. Either one of two techniques can be used in the field. First, a small card with stopwatch readings for all sampling points during the study period is prepared and the field crew takes a point sample at each reading. Second, the flyback feature of the stopwatch is used if the interval between samples is 13 seconds, with the crew chief calling out a cue at 13, 26, 39, 52, 05, 18, 31, 44, 57, and 10 seconds as read on the sweep hand. Approximately one-half second before reaching the last of these points, the second hand is brought back to zero using the flyback feature, and the stopwatch continues in motion from zero. This latter technique eliminates the need to look at a list of readings but does require that the crew chief memorize the 10 readings and that the stopwatch be carefully used so that time is not "lost" in resetting the sweep hand.

For studies based on a 15-second interval between samples there is no need to use either a list of readings or the flyback technique. Rather, point samples are simply taken at 15, 30, 45, and 60 seconds on the sweep hand.

In summary, either a stopwatch or a cassette recorder should be used for the interval timing device, although the latter is preferred.

Timer for Study Period (1 per team) - the crew chief will use an accurate wrist watch or a stopwatch with which the length of study will be timed. This watch will be read at zero or an even minute at the beginning of the study and a reading will be taken at the final sampling point to determine the total elapsed time of the study.

Other Equipment - each team member needs a clipboard, pencils, and enough data sheets for the periods to be studied. Each data sheet accommodates 120 point samples. A blank sheet is found at the end of this manual. A small chair or stool for each team member is useful, and an automobile should be available if poor weather is expected and the observation point at the intersection is not sheltered.

3.5 FIELD PROCEDURES

The step-by-step procedure for performing the Intersection Delay Study is as follows.

Step 1 - upon arrival at the site the crew chief checks the suggested observation point to ensure that a good view of stopped queues is available. If blockage of view occurs due to parked vehicles, sidewalk activity, etc., an alternative observation point is selected.

Step 2 - if a doubt exists as to traffic signal timing, the crew chief performs a check by using a stopwatch to time three signal cycles, from end of green on the main street to the next end of green on the main street. If all three cycles conform to a cycle length of 45, 60, 75, 90, 105, 120, 135, or 150 seconds, a 13-second interval between samples is used. If not, a 15-second interval is used.

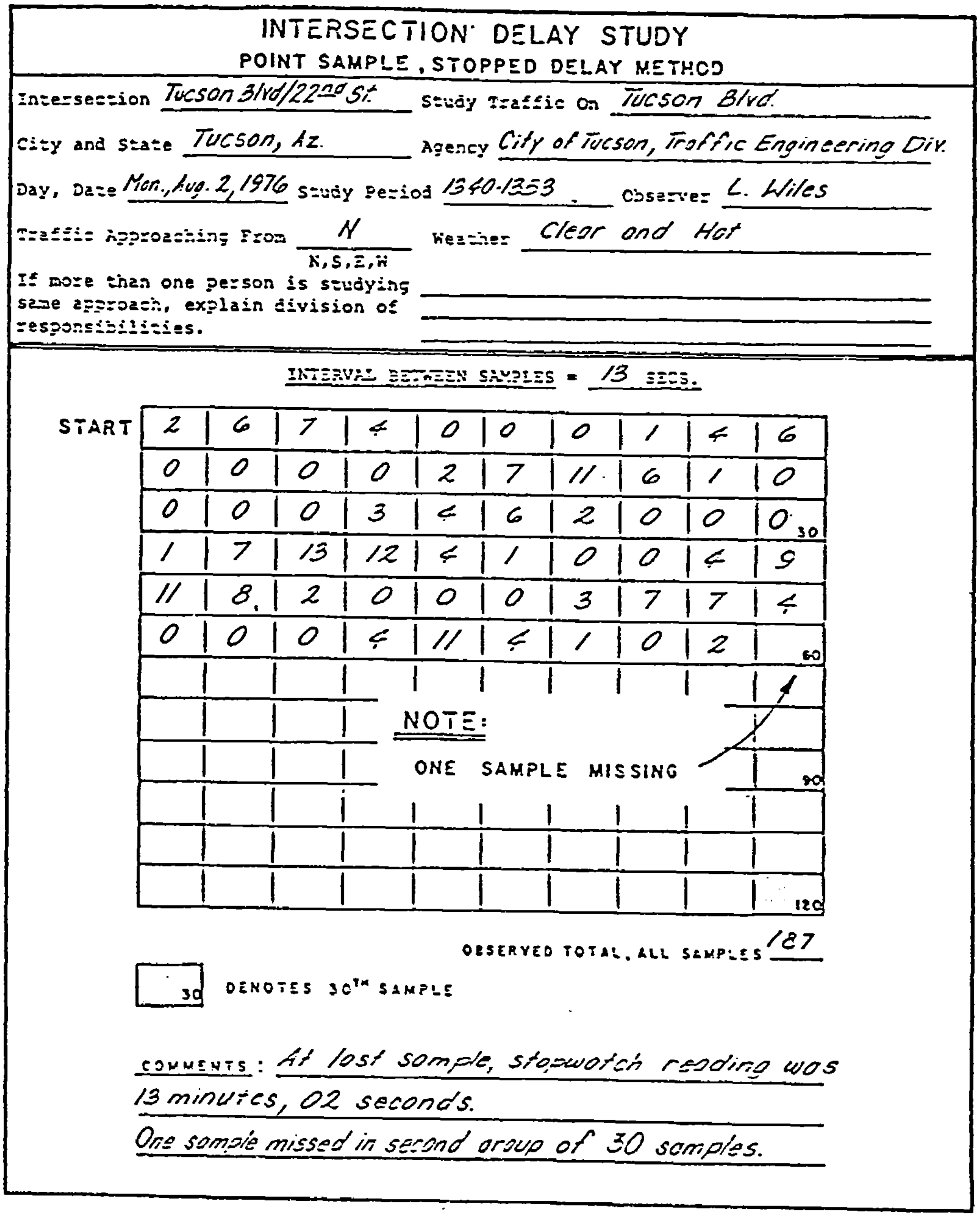
Step 3 - if more than one person is used for the Intersection Delay Study, the crew chief assigns specific lanes of the approach to each person. Then, at each sampling point, each delay observer (the crew chief is one of the delay observers) records the number of stopped vehicles in those lanes for which he or she is responsible.

Step 4 - each delay observer fills out the general information at the top of the data sheet, making sure that the interval between samples which is to be used is noted. Exhibit 2 shows a typical set of data on the Intersection Delay Study field data sheet.

Step 5 - at the proper time of day, the crew chief begins the study by setting both the "timing device for sampling points" (either a stopwatch or a cassette recorder) and the "timer for study period" in motion. At the same instant, the crew chief signals to all other persons, including those performing the Percent Stopping Study, that the study period has begun.

Step 6 - at time zero of the study no point sample is taken. At the first cue, which occurs at either 13 or 15 seconds, each observer notes the number of vehicles stopped at that instant and records this number on the data sheet. Each successive sampling point is identical in operation in that the delay observer notes and records the number of vehicles stopped at the instant the cue is given.

EXHIBIT 2. INTERSECTION DELAY STUDY, FIELD DATA SHEET



INTERSECTION DELAY STUDY

POINT SAMPLE, STOPPED DELAY METHOD

Intersection *Tucson Blvd/22nd St.* Study Traffic On *Tucson Blvd.*

City and State *Tucson, Az.* Agency *City of Tucson, Traffic Engineering Div.*

Day, Date *Mon., Aug. 2, 1976* Study Period *1340-1353* Observer *L. Wiles*

Traffic Approaching From *N* (N,S,E,W) Weather *Clear and Hot*

If more than one person is studying same approach, explain division of responsibilities.

INTERVAL BETWEEN SAMPLES = *13* SECS.

START	2	6	7	4	0	0	0	1	4	6
	0	0	0	0	2	7	11	6	1	0
	0	0	0	3	4	6	2	0	0	0 30
	1	7	13	12	4	1	0	0	4	9
	11	8	2	0	0	0	3	7	7	4
	0	0	0	4	11	4	1	0	2	60
										90
										120

NOTE:
ONE SAMPLE MISSING

OBSERVED TOTAL, ALL SAMPLES *187*

30 DENOTES 30TH SAMPLE

COMMENTS: *At last sample, stopwatch reading was 13 minutes, 02 seconds.*
One sample missed in second group of 30 samples.

Figure B-2. Intersection Delay Study, Field Data Sheet

Step 7 - at the end of each 30th sampling interval a message on the cassette will indicate the number of sampling points (either 30, 60, 90, or 120) which have passed since time zero. If an observer has not yet reached the shaded box (see Exhibit 2) on the data sheet, one or more samples has been missed. At the next sampling point, such as the 31st, the sample is entered in the 31st box, leaving one or more boxes blank for later adjustment in the office. Observers are instructed not to try to guess what the missing value might be but rather to leave the box(es) blank.

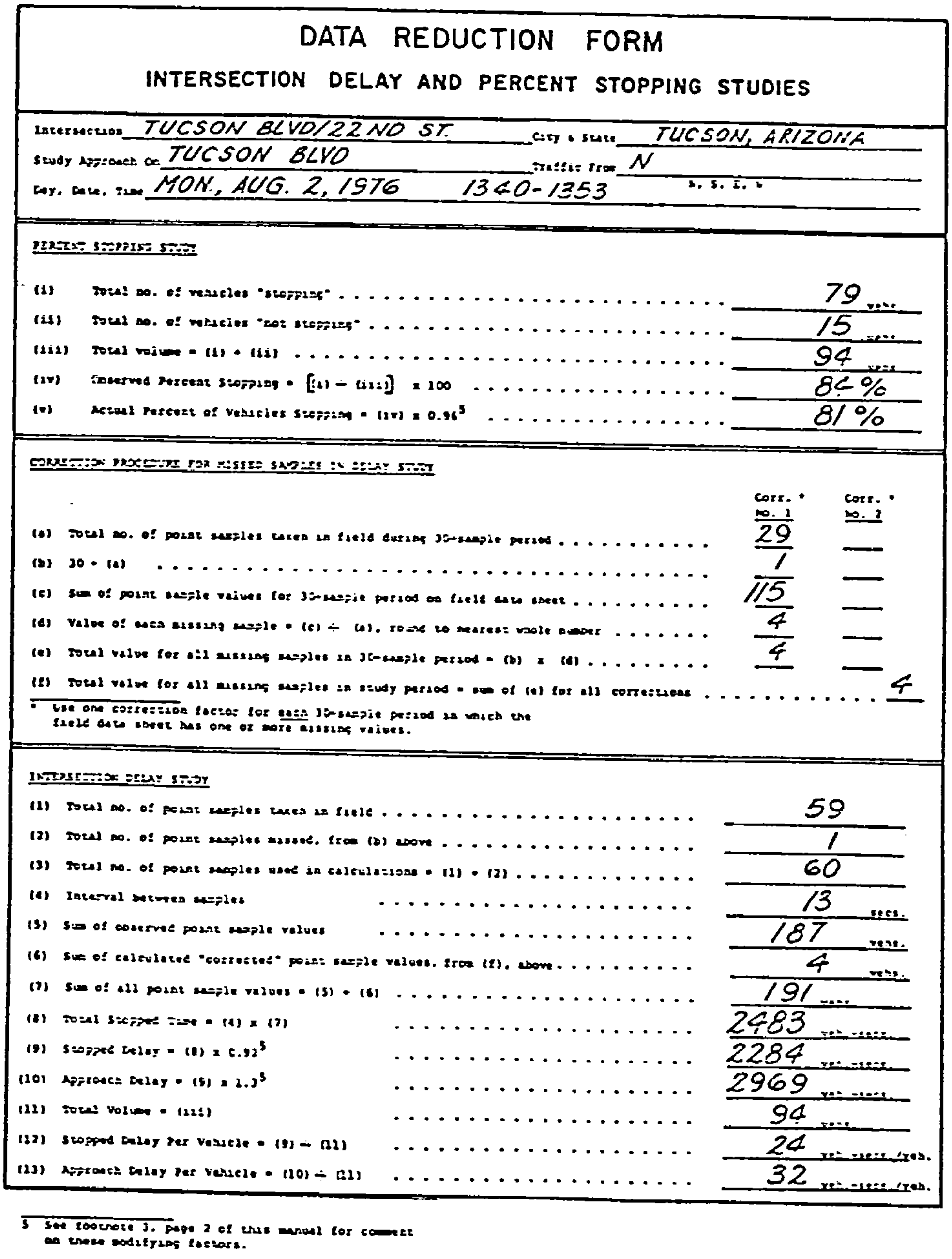
Step 8 - at the end of the required number of samples, the crew chief signals to all others that the study has ended and reads the study timer to obtain the total elapsed time of the study. This time is noted on the data sheet under "Comments." It is important that the signal at the beginning and at the end of the study be given exactly at the zero point and the final sampling point, respectively, so that observers performing the Percent Stopping Study can begin and end their count at the proper time.

Instructions to observers as to which vehicles are included in the sample of stopped vehicles at each sampling point are as follows:

- a vehicle with locked wheels (no motion) is counted.
- a vehicle that had previously come to a stop and is creeping (at the instant a point sample is taken) in a stopped queue which is not discharging from the intersection is classified in the following manner: it is considered as "stopped" if a gap of less than or equal to 50 feet (15 meters) or about three car lengths, exists between it and the vehicle in front of it; it is considered to be "moving" (and thus is not counted in the point sample of stopped vehicles) if the gap to the next vehicle is greater than 50 feet (15 meters).

Two additional points are important. First, when two persons are used to perform the Intersection Delay Study it is recommended that they stand relatively close together so that an audible cue, either from a cassette or from the crew chief, can be heard by both. If it becomes absolutely necessary for one delay observer to move away from the other, a prearranged system of audible or visual cues is used to signal each sampling point. One problem encountered with audible cues is that they can be missed if traffic noise becomes intense.

EXHIBIT 3. DATA REDUCTION FORM



DATA REDUCTION FORM

INTERSECTION DELAY AND PERCENT STOPPING STUDIES

Intersection TUCSON BLVD/22ND ST. City & State TUCSON, ARIZONA
Study Approach On TUCSON BLVD Traffic from N
Day, Date, Time MON., AUG. 2, 1976 1340-1353 N, S, E, W

PERCENT STOPPING STUDY

(i) Total no. of vehicles "stopping" .... 79 vehs.
(ii) Total no. of vehicles "not stopping" .... 15 vehs.
(iii) Total volume = (i) + (ii) .... 94 vehs.
(iv) Observed Percent Stopping = [(i) ÷ (iii)] x 100 .... 84 %
(v) Actual Percent of Vehicles Stopping = (iv) x 0.96[5] .... 81 %

CORRECTION PROCEDURE FOR MISSED SAMPLES IN DELAY STUDY

	Corr.* No. 1	Corr.* No. 2
(a) Total no. of point samples taken in field during 30-sample period	29	
(b) 30 − (a)	1	
(c) Sum of point sample values for 30-sample period on field data sheet	115	
(d) Value of each missing sample = (c) ÷ (a), round to nearest whole number	4	
(e) Total value for all missing samples in 30-sample period = (b) x (d)	4	

(f) Total value for all missing samples in study period = sum of (e) for all corrections 4

* Use one correction factor for each 30-sample period in which the field data sheet has one or more missing values.

INTERSECTION DELAY STUDY

(1) Total no. of point samples taken in field 59
(2) Total no. of point samples missed, from (b) above 1
(3) Total no. of point samples used in calculations = (1) + (2) 60
(4) Interval between samples .... 13 secs.
(5) Sum of observed point sample values .... 187 vehs.
(6) Sum of calculated "corrected" point sample values, from (f), above .... 4 vehs.
(7) Sum of all point sample values = (5) + (6) .... 191 vehs.
(8) Total Stopped Time = (4) x (7) .... 2483 veh.-secs.
(9) Stopped Delay = (8) x 0.92[5] .... 2284 veh.-secs.
(10) Approach Delay = (9) x 1.3[5] .... 2969 veh.-secs.
(11) Total Volume = (iii) .... 94 vehs.
(12) Stopped Delay Per Vehicle = (9) ÷ (11) .... 24 veh.-secs./veh.
(13) Approach Delay Per Vehicle = (10) ÷ (11) .... 32 veh.-secs./veh.

---

[5] See footnote 3, page 2 of this manual for comment on these modifying factors.

Figure B-3. Data Reduction Form

Second, the delay observers should be made aware of the fact that the most difficult point to sample is just after the traffic signal has turned green and the front end of a stopped queue is moving. The observer should make a mental note of all vehicles which are stopped at the instant of the sampling point. Then the observer can take a few seconds to count all of these vehicles.

3.6 DATA REDUCTION

In the office, a data reduction form is filled out for each study period. This form, an example of which is given as Exhibit 3, contains space for reduction of data from both the Intersection Delay Study and the Percent Stopping Study. A blank data reduction form is found at the end of this manual.

Data reduction is performed in the following steps.

Step 1 - if the Percent Stopping Study (see Section 4 for description) was performed simultaneously with the Intersection Delay Study, the percent stopping data are entered on the data reduction form (lines i, ii) and a simple division yields the percent stopping figure.

Step 2 - a count of total volume during the study period is entered on line 7. The count is normally taken from the Percent Stopping Study (line iii) but may come from a simple manual or mechanical count.

Step 3 - if one or more point samples was missed in the field a correcting procedure is used (lines a through f). The average value for all samples taken during each period of 30 samples is used as the estimate for any missing values during that same period.

Step 4 - a check is made of the elapsed time of the study as noted by the crew chief under "Comments" on the field sheet. If the elapsed time is not within 30 seconds of the product of the interval between samples and the total number of samples (including those missed) it is recommended that the study be repeated or that a correction factor be applied to the value for interval between samples (line 4). The corrected interval, in seconds, is the total elapsed study time divided by the number of sampling points (60, 90, or 120). If no correction is indicated, the value found at the top of the field data sheet is entered on line 4 of the data reduction form.

Step 5 - on the field data sheet, all observed samples are summed and the total is placed at the bottom of the sheet.

Step 6 - using data from the field sheet, lines 1 and 5 are filled in on the data reduction form. If two observers were used for the Intersection Delay Study it will be necessary to add the values from each of their field sheets to arrive at a total for the entire study approach.

Step 7 - lines 6 through 13 are completed as per instructions on the data reduction form itself.

3.7 PRESENTATION OF RESULTS

The measures which can be estimated from the Intersection Delay Study are (note that "line" numbers refer to data reduction form):

- Stopped Delay, in vehicle-seconds (line 9)
- Approach Delay, in vehicle-seconds (line 10)
- Stopped Delay Per Vehicle, in vehicle-seconds per vehicle (line 12)
- Approach Delay Per Vehicle, in vehicle-seconds per vehicle (line 13)

The latter two measures require a volume count for their computation. This volume count will normally be obtained by using the Percent Stopping Study.

In general, the best measure to use in comparing efficiency of intersection operation or for setting priorities for improvement projects is approach delay per vehicle. However, for some uses related to idling costs, the stopped delay per vehicle figure might be more applicable.

In presenting results, an explicit identification of the delay type is essential and the abovementioned terms, rather than the vague term "delay" should be used.

APPENDIX C

TYPICAL PLOT OF ESTIMATED DELAY VS. OBSERVED DELAY (ACTUAL) PER STOPPED VEHICLE FOR THE PEAK PERIOD

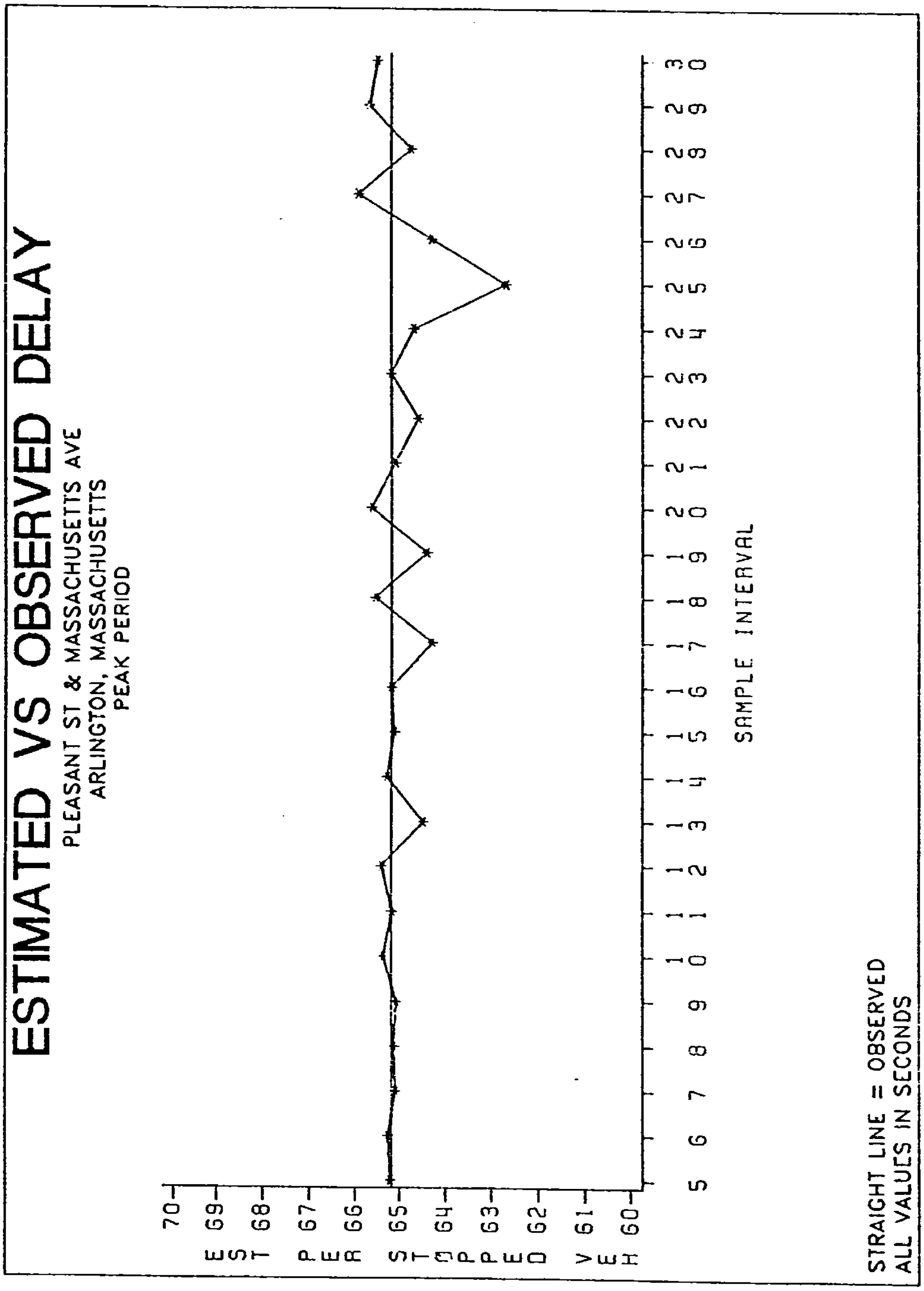


Figure C-1. Estimated Vs Observed Delay Per Stopped Vehicle Pleasant St. Arlington, Massachusetts-Peak Period

APPENDIX D

TYPICAL PLOT OF ESTIMATED DELAY VS. OBSERVED DELAY (ACTUAL) PER APPROACH VEHICLE FOR THE PEAK PERIOD

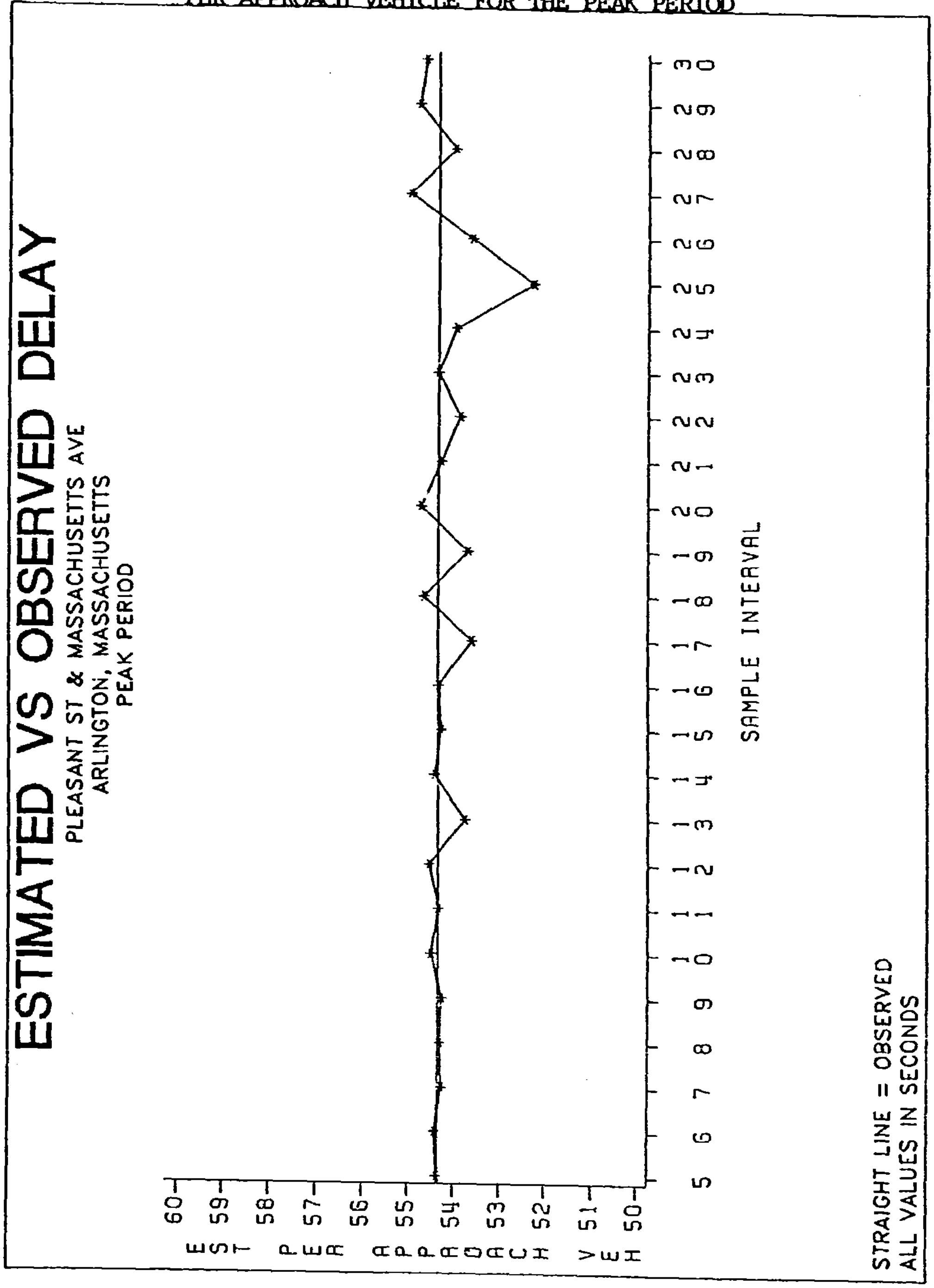


Figure D-1. Estimated Vs Observed Delay Per Approach Vehicle Pleasant St. Arlington, Massachusetts - Peak Period

APPENDIX E

SAS TWO-FACTOR FACTORIAL ANOVA WITH PLOTS TO CHECK MODEL ADEQUACY AND A SPSS-X TUKEY TEST FOR ADDITIVITY

```
                                    ANALYSIS OF SAMPLE INTERVAL
                         ESTIMATED VS OBSERVED DELAY PER APPROACH VEHICLE
                                   PEAK DATA  7 OUTLIERS DELETED
                                  GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: DIFF

SOURCE                DF      SUM OF SQUARES        MEAN SQUARE       F VALUE       PR > F       R-SQUARE         C.V.

MODEL                 34          1.39271713         0.04096227          0.78       0.8028       0.109072     594.2196

ERROR                217         11.37603952         0.05242415                    ROOT MSE                   DIFF MEAN

CORRECTED TOTAL      251         12.76875675                                      0.22896320                -0.03353175

SOURCE                DF          TYPE I SS     F VALUE     PR > F        DF       TYPE III SS      F VALUE      PR > F

INTERVAL              25          0.94143232       0.72     0.8361        25        0.95041619         0.73      0.8289
SAMPLE                 9          0.45123483       0.96     0.4777         9        0.45123433         0.96      0.4777
```

Figure E-1. ANOVA - Sample Interval and Sample (Intersection/Film No.) Delay Per Approach Vehicle - Peak Period

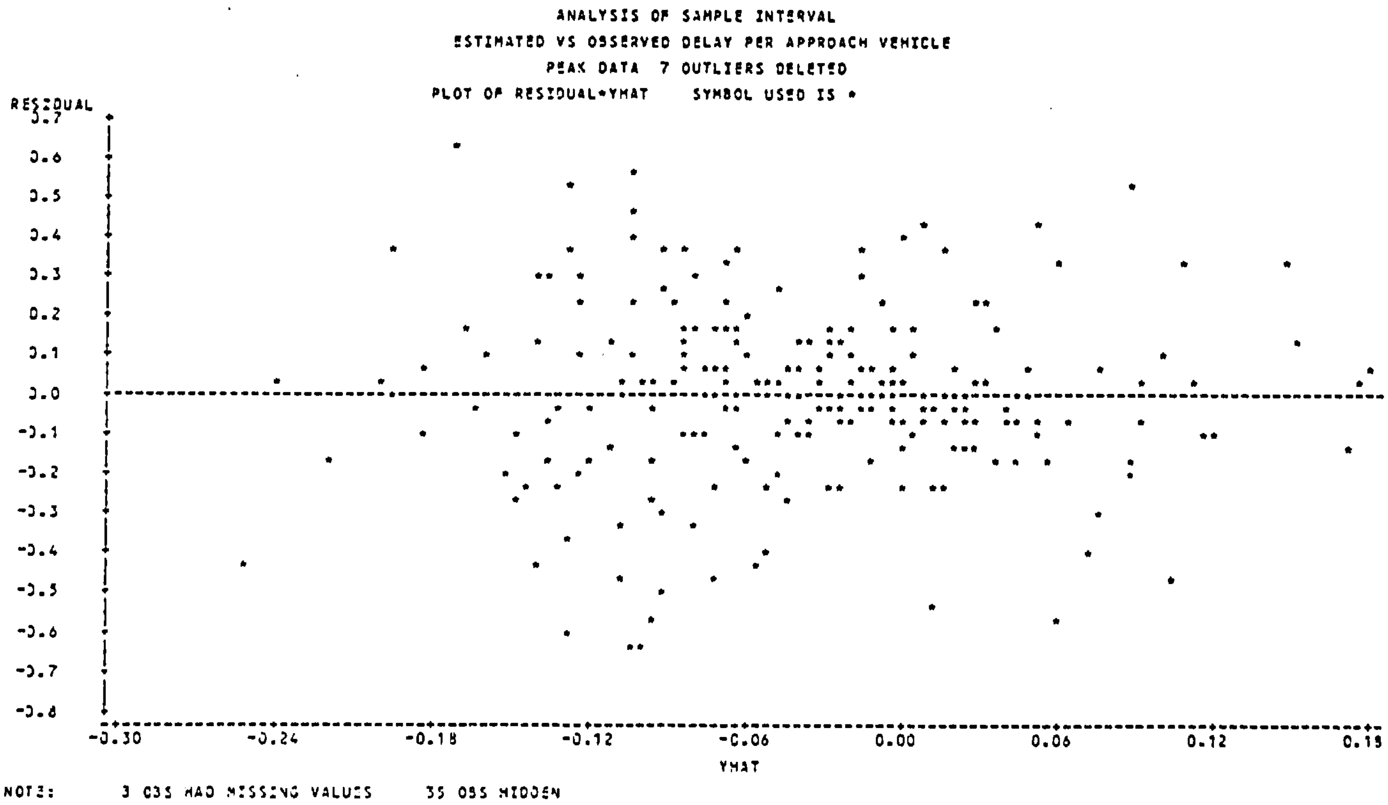


Figure E-2. Plot of Residuals Vs $\widehat{Y}$ (Yhat) - Sample Interval - Delay Per Approach Vehicle - Peak Period

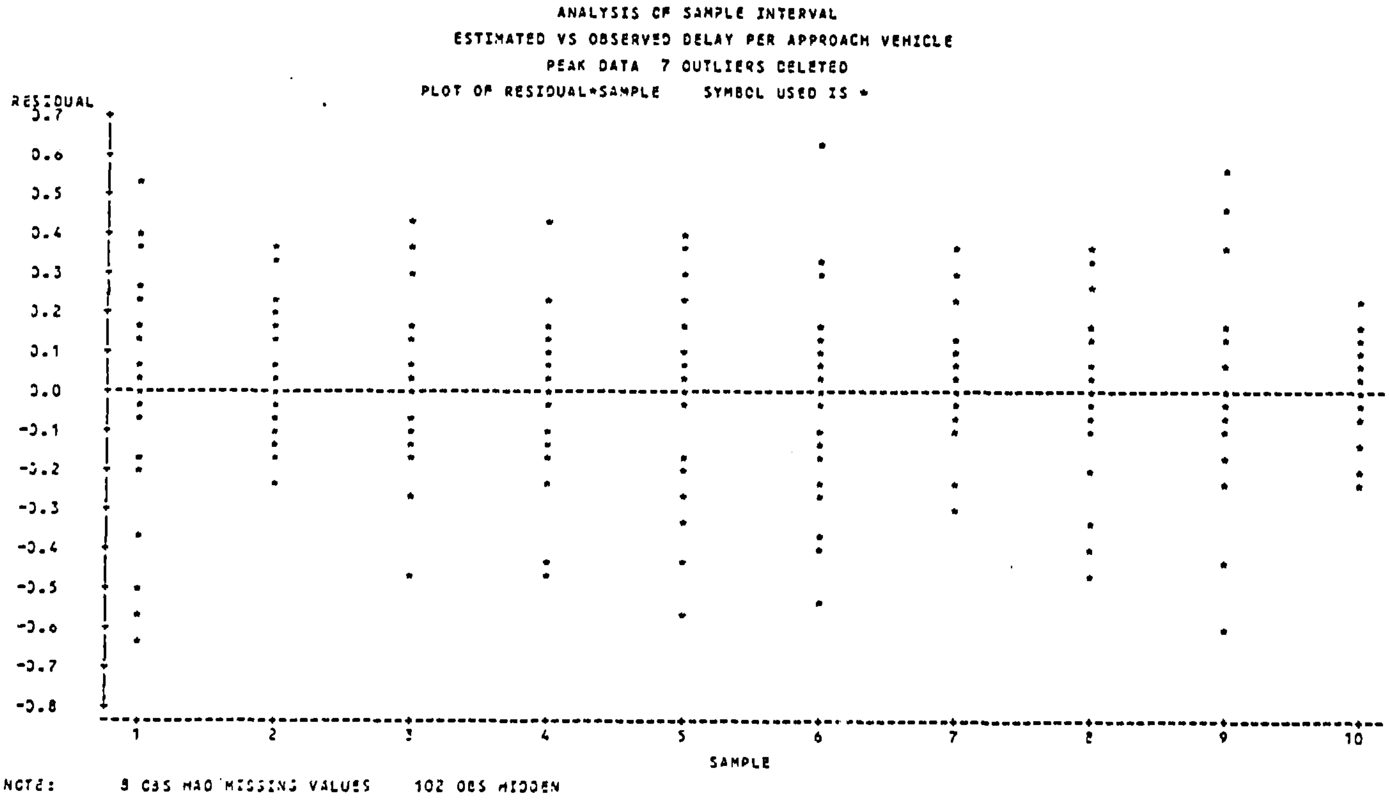
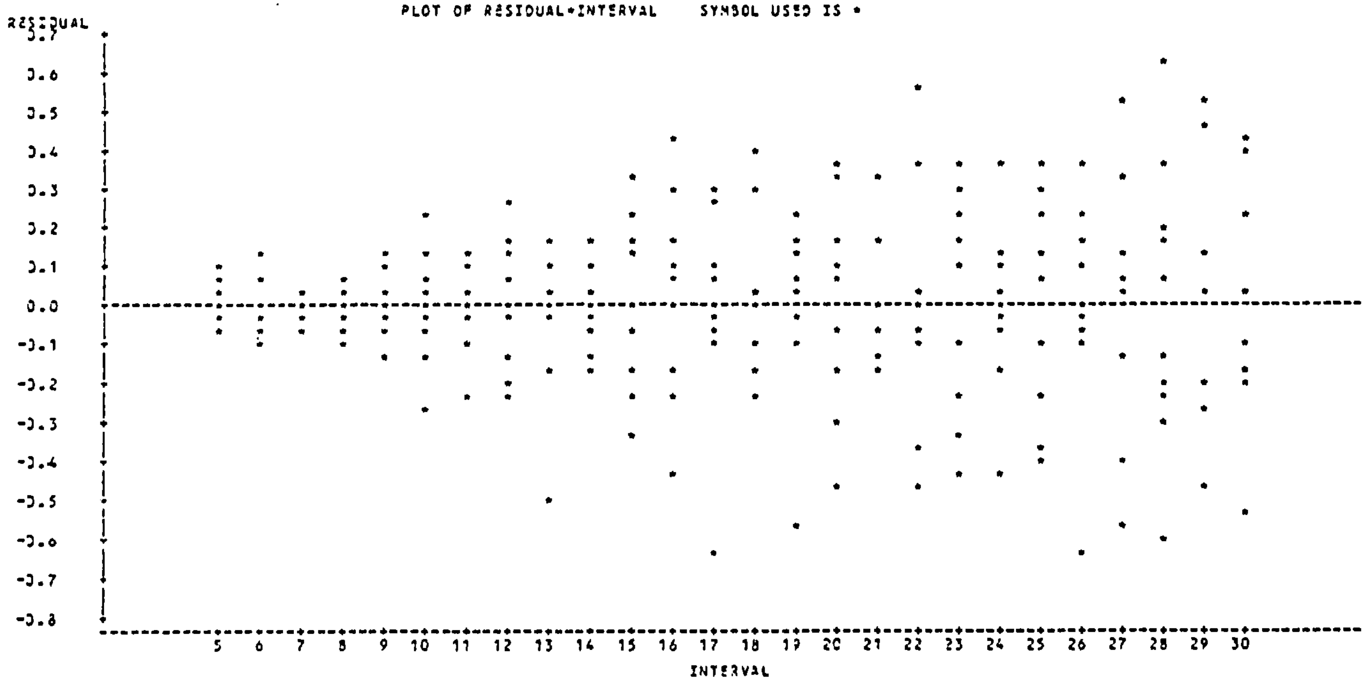


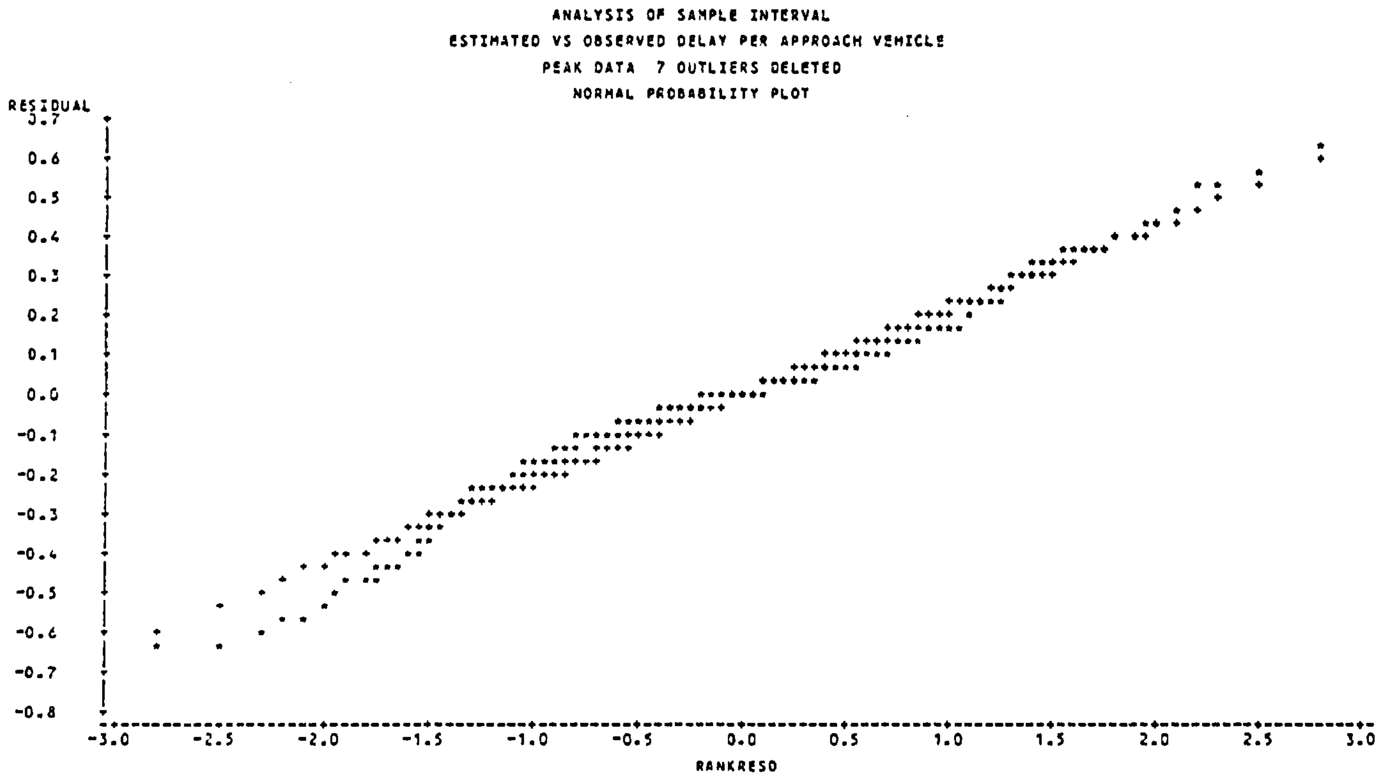
Figure E-3. Plot of Residuals Vs Sample (Intersection/Film No.) - Delay Per Approach Vehicle - Peak Period

```
ANALYSIS OF SAMPLE INTERVAL
ESTIMATED VS OBSERVED DELAY PER APPROACH VEHICLE
PEAK DATA  7 OUTLIERS DELETED
PLOT OF RESIDUAL*INTERVAL     SYMBOL USED IS *
```



```
NOTE:     3 OBS HAD MISSING VALUES     49 OBS HIDDEN
```

Figure E-4. Plot of Residuals Vs Interval in Seconds - Delay Per Approach Vehicle - Peak Period



NOTE: 16 OBS HAD MISSING VALUES 297 OBS HIDDEN

Figure E-5 Normal Probability Plot - Sample Interval - Delay Per Approach Vehicle - Peak Period

ANALYSIS OF SAMPLE INTERVAL
ESTIMATED VS OBSERVED DELAY PER APPROACH VEHICLE
PEAK DATA 7 OUTLIERS DELETED
HISTOGRAM OF RESIDUALS
FREQUENCY BAR CHART

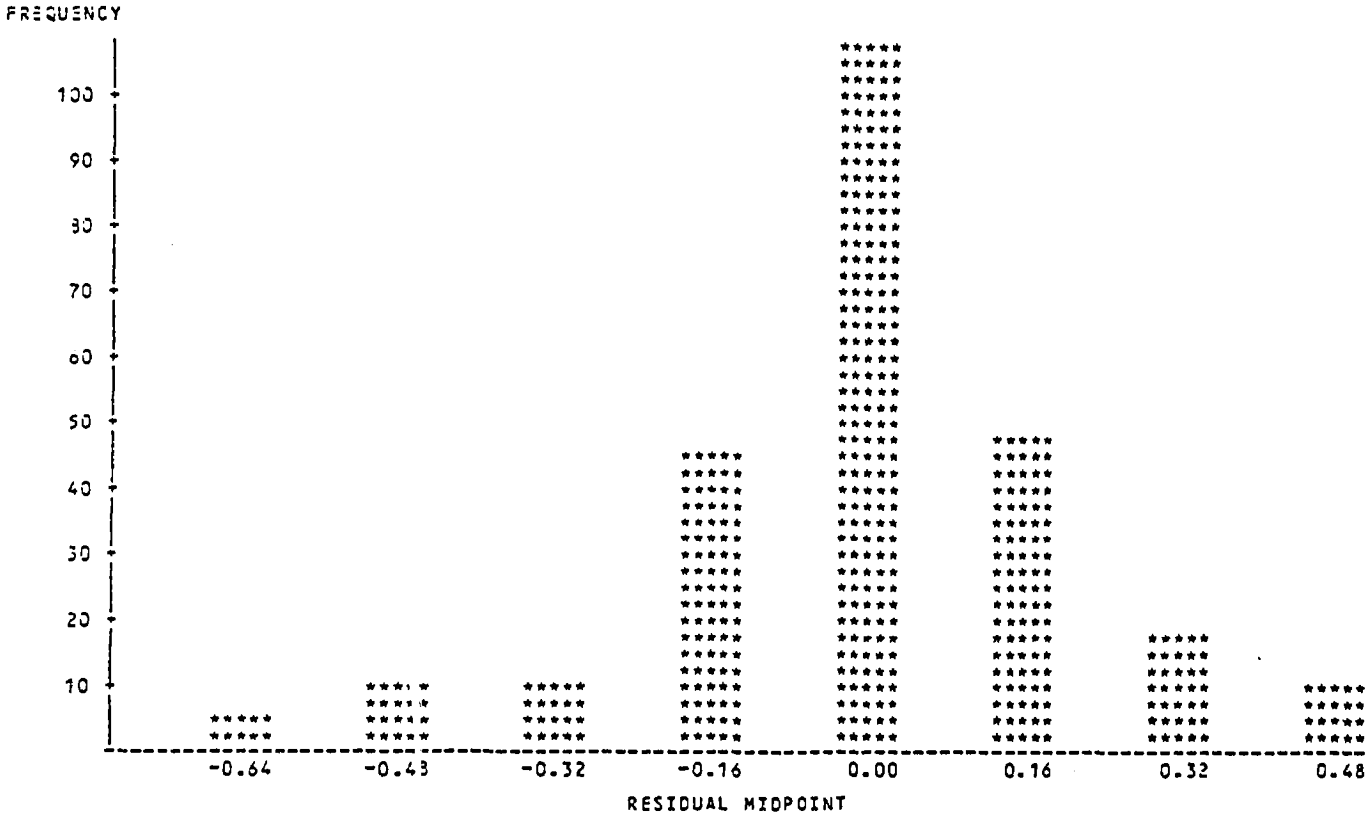


Figure E-6. Histogram of Residuals - Sample Interval - Delay Per Approach Vehicle - Peak Period

```
11 JUL 85    TWO-WAY FACTORIAL ANOVA WITH ONE OBS PER CELL TUKEY TEST
17:07:29     FOR ADDITIVITY (PEAK DATA PER APPR VEH 7 OUTLIERS DEL)

                      R E L I A B I L I T Y   A N A L Y S I S   -   S C A L E   (D I F F)

  1.      SAMPLE1
  2.      SAMPLE2
  3.      SAMPLE3
  4.      SAMPLE4
  5.      SAMPLE5
  6.      SAMPLE6
  7.      SAMPLE7
  8.      SAMPLE8
  9.      SAMPLE9
 10.      SAMPLE10

                          MEAN         STD DEV       CASES

  1.      SAMPLE1        -.1574         .3205         19.0
  2.      SAMPLE2        -.0174         .1402         19.0
  3.      SAMPLE3         .0375         .1712         19.0
  4.      SAMPLE4        -.0579         .1709         19.0
  5.      SAMPLE5        -.1384         .2180         19.0
  6.      SAMPLE6        -.0311         .1905         19.0
  7.      SAMPLE7        -.0363         .1339         19.0
  8.      SAMPLE8        -.0147         .1577         19.0
  9.      SAMPLE9        -.1263         .2158         19.0
 10.      SAMPLE10        .0153         .0937         19.0

                     ANALYSIS OF VARIANCE

SOURCE OF VARIATION     SUM OF SQ.      DF     MEAN SQUARE        F          PROB.

BETWEEN PEOPLE             .3798        13         .0211
WITHIN PEOPLE             6.9377       171         .0406
  BETWEEN MEASURES          .7693         9        .0855        2.2449      .0217
  RESIDUAL                 6.1684       162        .0381
    NONADDITIVITY            .1874        1        .1874        5.0457      .0260
    BALANCE                 5.9309       161       .0371
TOTAL                     7.3175       139         .0387

     GRAND MEAN =         -0.0535

TUKEY ESTIMATE OF POWER TO WHICH OBSERVATIONS
MUST BE RAISED TO ACHIEVE ADDITIVITY           =        0.4096
```

Figure E-7 Tukey Test For Additivity - Sample Interval -
Delay Per Approach Vehicle - Peak Period

APPENDIX F

TYPICAL LINEAR REGRESSION ANALYSIS PLOTS

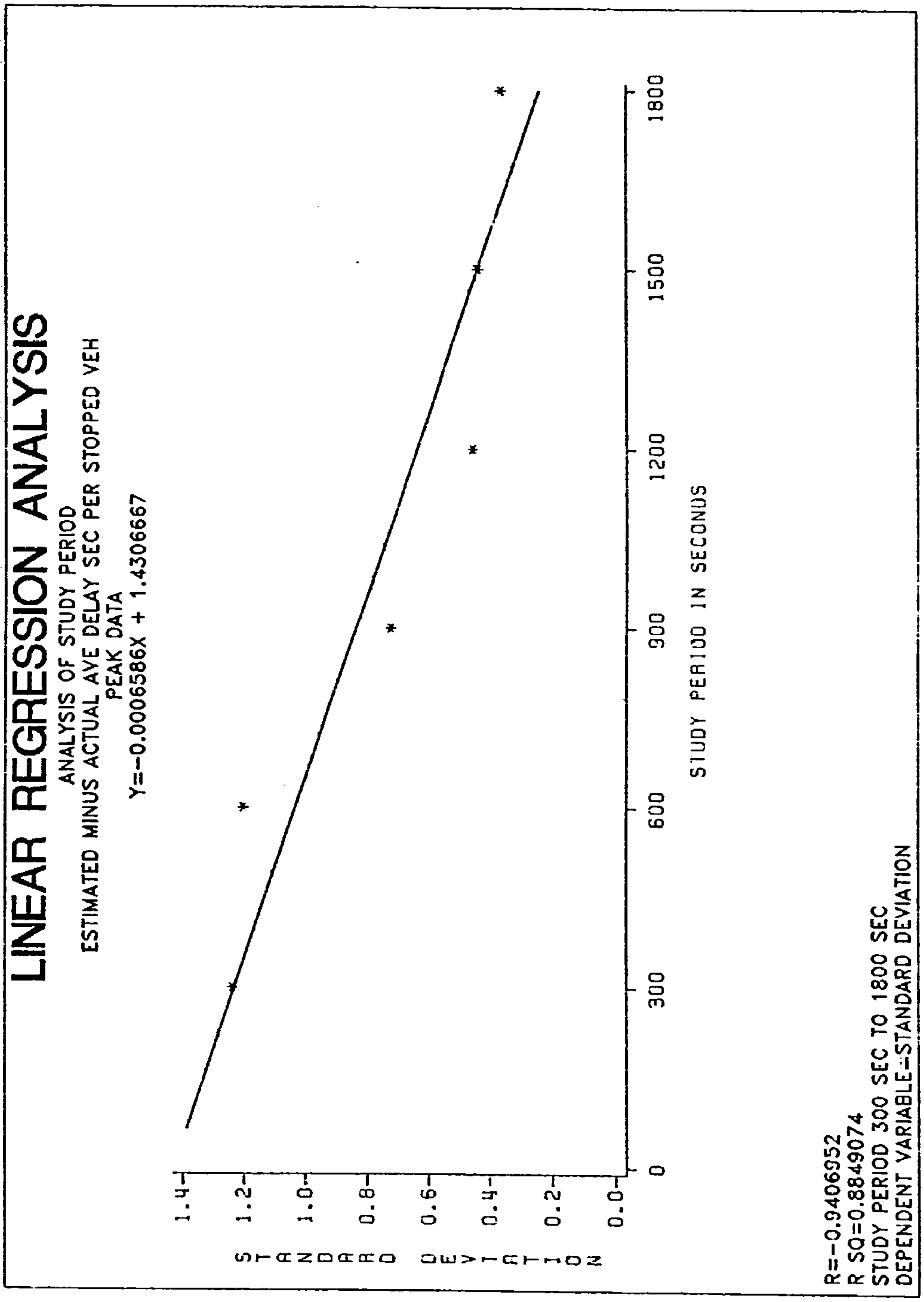


Figure F-1. Linear Regression Plot - Standard Deviation Vs Study Period in Seconds - Delay Per Stopped Vehicle - Peak Period

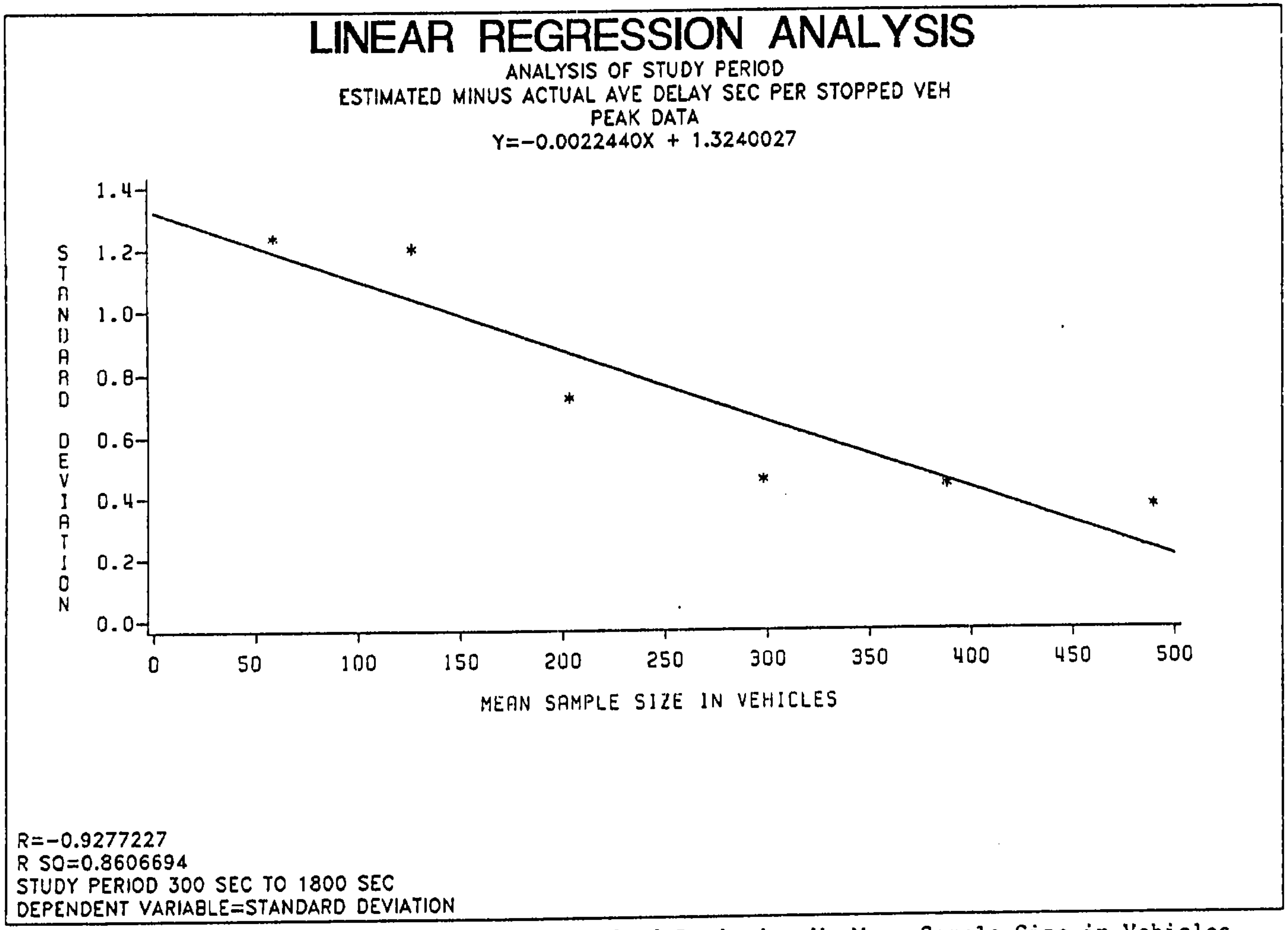


Figure F-2. Linear Regression Plot - Standard Deviation Vs Mean Sample Size in Vehicles - Study Period 300 to 1800 Sec. - Delay Per Stopped Vehicle - Peak Period

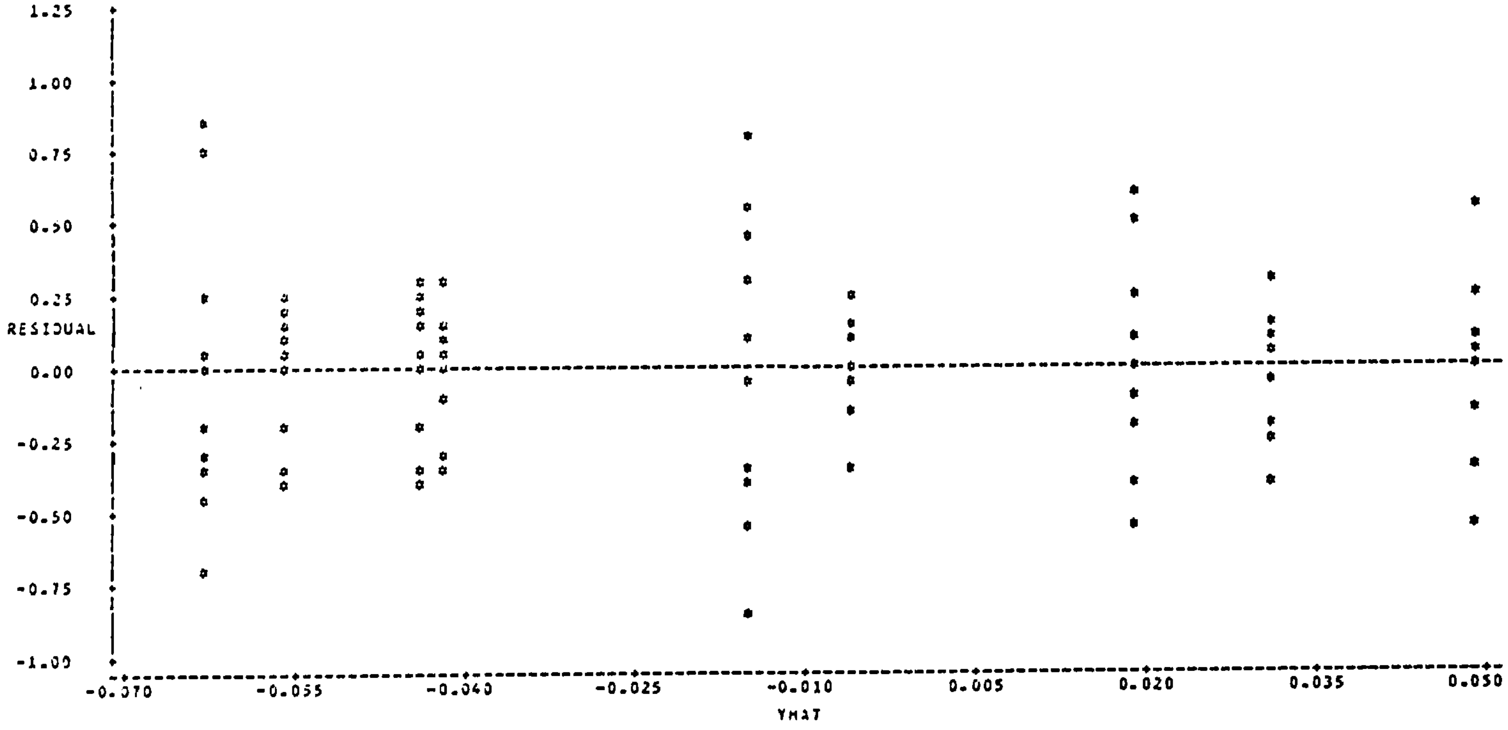
APPENDIX G

SAS ONE-WAY ANOVA WITH PLOTS TO CHECK MODEL ADEQUACY

```
                                          ANALYSIS OF STUDY PERIOD                         12:45 FRIDAY, AUGUST 30, 1985   4
                                 ESTIMATED VS OBSERVED DELAY PER APPROACH VEHICLE
                            15 SECOND SAMPLE INTERVAL OFF-PEAK DATA 0 OUTLIERS DELETED
                                         GENERAL LINEAR MODELS PROCEDURE
DEPENDENT VARIABLE: DIFF
SOURCE                  DF          SUM OF SQUARES        MEAN SQUARE        F VALUE          PR > F        R-SQUARE          C.V.
MODEL                    8              0.12996889         0.01624611           0.14          0.9969        0.013922     2389.0612
ERROR                   81              9.20581000         0.11365198                       ROOT MSE                     DIFF MEAN
CORRECTED TOTAL         89              9.33577889                                        0.33712309                   -0.01411111

SOURCE                  DF               TYPE I SS      F VALUE        PR > F         DF          TYPE III SS       F VALUE        PR > F
PERIOD                   8              0.12996889         0.14        0.9969          8           0.12996889          0.14        0.9969

OBSERVATION           OBSERVED              PREDICTED              RESIDUAL
                        VALUE                 VALUE

         1          0.77000000           -0.06300000            0.83300000
         2         -0.41000000           -0.06300000           -0.34700000
         3         -0.07000000           -0.06300000           -0.00700000
         4          0.21000000           -0.06300000            0.27300000
         5          0.71000000           -0.06300000            0.77300000
         6         -0.36000000           -0.06300000           -0.29700000
         7         -0.76000000           -0.06300000           -0.69700000
         8         -0.24000000           -0.06300000           -0.17700000
         9          0.01000000           -0.06300000            0.07300000
        10         -0.50000000           -0.06300000           -0.43700000
        11          0.52000000           -0.01500000            0.53500000
        12          0.09000000           -0.01500000            0.10500000
        13         -0.04000000           -0.01500000           -0.02500000
        14         -0.56000000           -0.01500000           -0.54500000
        15          0.78000000           -0.01500000            0.79500000
        16          0.28000000           -0.01500000            0.29500000
        17         -0.43000000           -0.01500000           -0.41500000
        18          0.45000000           -0.01500000            0.46500000
        19         -0.36000000           -0.01500000           -0.34500000
        20         -0.37000000           -0.01500000           -0.35500000
        21          0.60000000            0.01900000            0.58100000
        22          0.11000000            0.01900000            0.09100000
        23         -0.07000000            0.01900000           -0.08900000
        24         -0.17000000            0.01900000           -0.18900000
        25          0.51000000            0.01900000            0.49100000
        26          0.04000000            0.01900000            0.02100000
        27         -0.17000000            0.01900000           -0.18900000
        28          0.28000000            0.01900000            0.26100000
        29         -0.55000000            0.01900000           -0.56900000
        30         -0.39000000            0.01900000           -0.40900000
        31          0.28000000            0.04900000            0.23100000
        32          0.05000000            0.04900000            0.00100000
        33          0.17000000            0.04900000            0.12100000
```

Figure G-1. ANOVA - Length of Study Period - Delay Per Approach Vehicle - 15-Second Sample Interval - Off-Peak Period

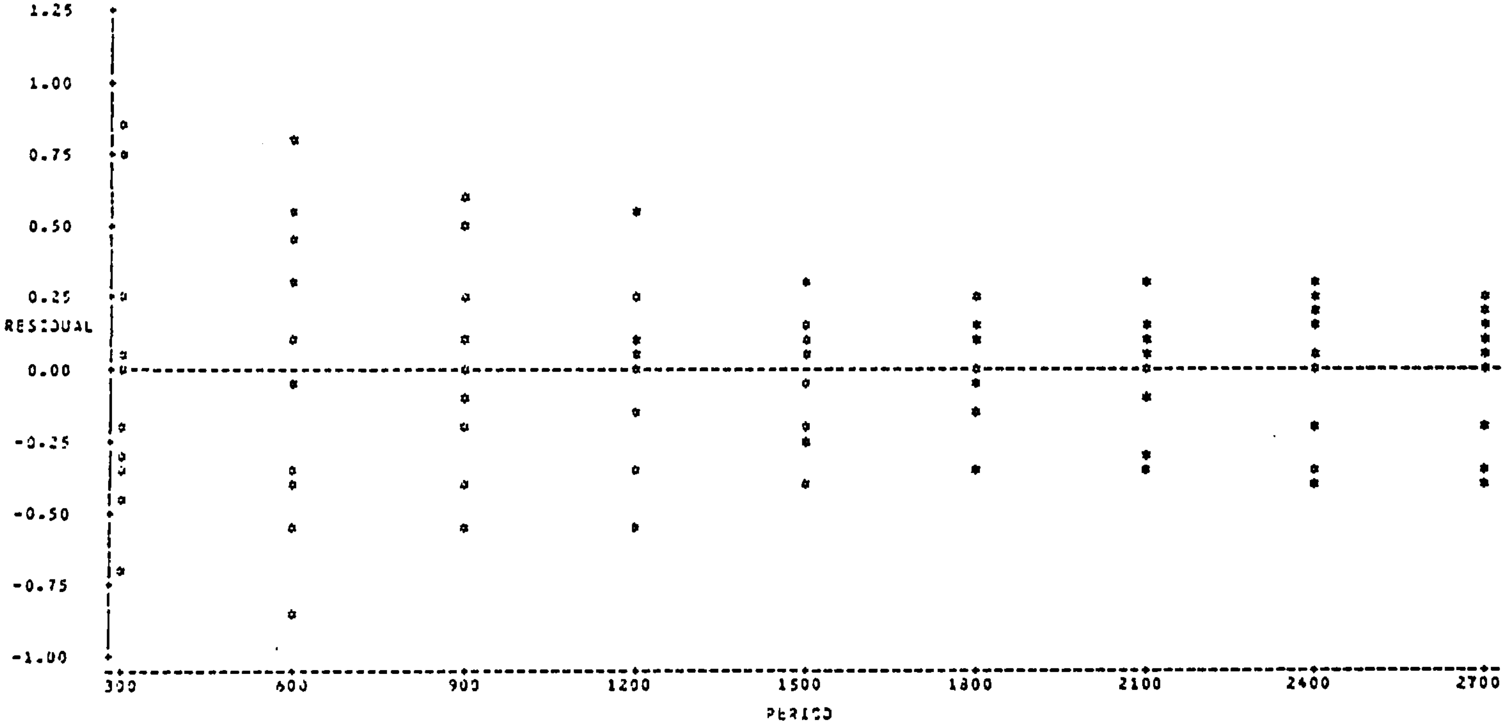
```
                    ANALYSIS OF STUDY PERIOD                    12:45 FRIDAY, AUGUST 30, 1985   1C
          ESTIMATED VS OBSERVED DELAY PER APPROACH VEHICLE
     15 SECOND SAMPLE INTERVAL OFF-PEAK DATA 0 OUTLIERS DELETED
        PLOT OF RESIDUAL*YHAT      SYMBOL USED IS *
```



NOTE: 12 OBS HIDDEN

Figure G-2. Plot of Residuals Vs $\hat{Y}$ (Yhat) - Study Period - Delay Per Approach Vehicle - 15-Second Sample Interval - Off-Peak Period

ANALYSIS OF STUDY PERIOD 12:45 FRIDAY, AUGUST 30, 1985 9
ESTIMATED VS OBSERVED DELAY PER APPROACH VEHICLE
15 SECOND SAMPLE INTERVAL OFF-PEAK DATA 0 OUTLIERS DELETED
PLOT OF RESIDUAL*PERIOD SYMBOL USED IS *



NOTE: 12 OBS HIDDEN

Figure G-3. Plot of Residuals Vs Period - Study Period - Delay Per Approach Vehicle - 15-Second Sample Interval - Off-Peak Period

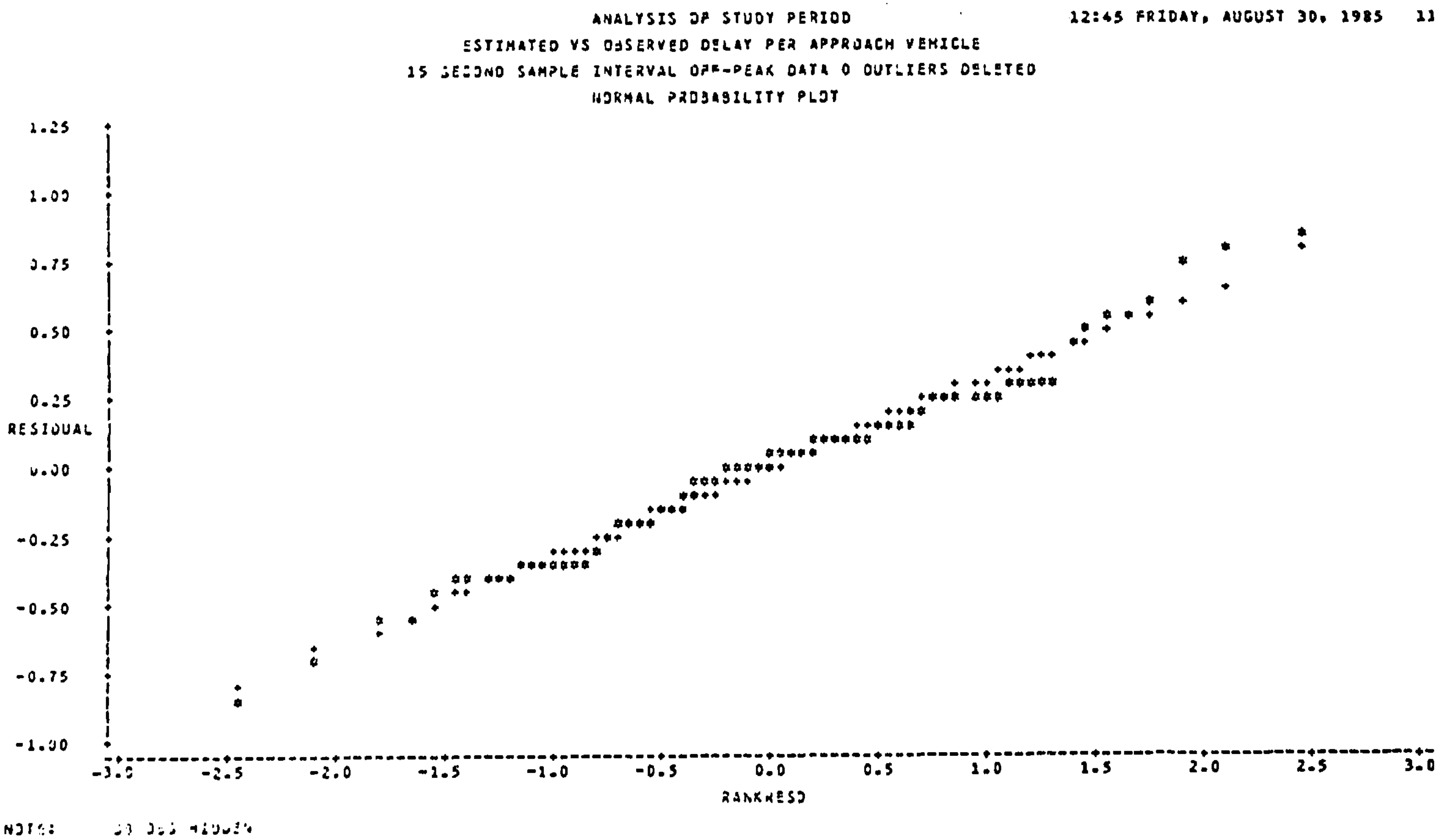


Figure G-4. Normal Probability Plot - Study Period - Delay Per Approach Vehicle - 15-Second Sample Interval - Off-Peak Period

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                    ANALYSIS OF STUDY PERIOD                    12:45 FRIDAY, AUGUST 30, 1985   12
           ESTIMATED VS OBSERVED DELAY PER APPROACH VEHICLE
       15 SECOND SAMPLE INTERVAL OFF-PEAK DATA 0 OUTLIERS DELETED
                     HISTOGRAM OF RESIDUALS
                     FREQUENCY BAR CHART
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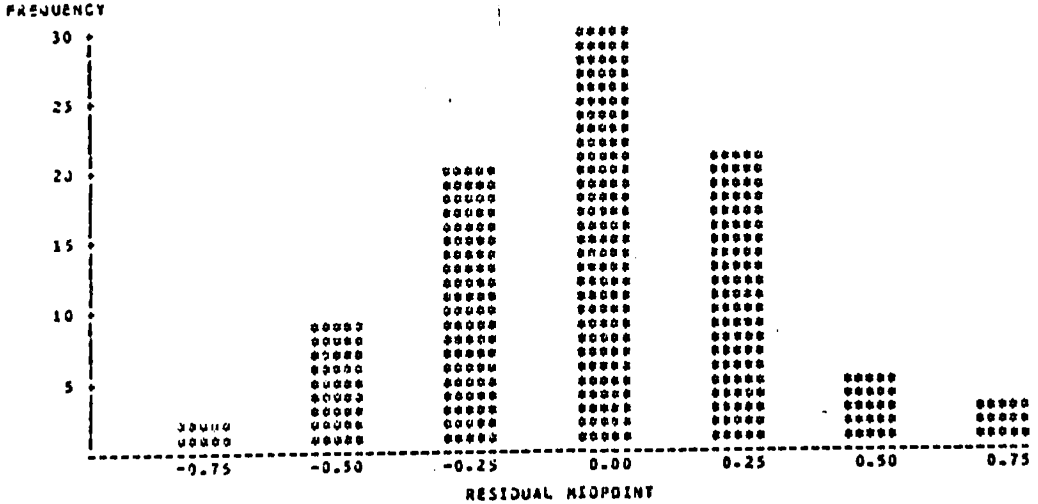

Figure G-5. Histogram of Residuals - Study Period - Delay Per Approach Vehicle - 15-Second Sample Interval - Off-Peak Period