EFFECTS OF A CHANGE IN THE CONTROL
DEVICE ON INTERSECTION ACCIDENTS

MAY 1966
NO. 6

Joint
Highway
Research
Project

PURDUE UNIVERSITY
LAFAYETTE INDIANA

by
G. W. SCHOENE

EFFECTS OF A CHANGE IN THE CONTROL DEVICE
ON
INTERSECTION ACCIDENTS

To: G. A. Leonards, Director
Joint Highway Research Project

May 10, 1966

From: H. L. Michael, Associate Director
Joint Highway Research Project

File: 8-5-7
Project: G-36-59G

The Final Report attached "Effects of a Change in the Control Device on Intersection Accidents" has been authored by Mr. George W. Schoene, Graduate Assistant on our staff. The research was directed by Professor H. L. Michael. Mr. Schoene also utilized the report as his thesis for the MSCE degree.

The research was conducted on accidents at 38 intersections in Indiana which had been changed from stop-sign control to traffic signal control. It was found that traffic accidents most often increased at these intersections following the installation of traffic signals. Right-angle accidents normally decreased slightly while rear-end accidents increased considerably. It was noted that at locations where five or more right angle accidents per year occurred under stop-sign control, a reduction in total accidents often occurred after traffic signals were installed.

The research was reported in a paper presented to the last Annual Purdue Road School. This report is presented for the record and for use by the Traffic Engineering Division of the Highway Commission.

Respectfully submitted, S.S.

Harold L. Michael

Harold L. Michael, Secretary

HLM:set

Attachment

Copy:

F. L. Ashbaucher
J. R. Cooper
J. W. Delleur
W. L. Dolch
W. H. Goetz
W. L. Grecco
G. K. Hallock
F. S. Hill
J. F. McLaughlin

F. B. Mendenhall
R. D. Miles
J. C. Oppenlander
W. P. Privette
M. B. Scott
K. B. Woods
E. J. Yoder

Digitized by the Internet Archive
in 2011 with funding from
LYRASIS members and Sloan Foundation; Indiana Department of Transportation

Final Report
EFFECTS OF A CHANGE IN THE CONTROL DEVICE
ON
INTERSECTION ACCIDENTS

by

George W. Schoene
Graduate Assistant

Joint Highway Research Project

Project No: C-36-59G
File No: 8-5-7

Purdue University
Lafayette, Indiana

May 10, 1966

ACKNOWLEDGMENTS

The author wishes to express his sincerest appreciation to Professor Harold L. Michael, Associate Director, Joint Highway Research Project, for the generous time and effort that he gave in the direction of this study and his critical review of the manuscript; to Professor J. C. Oppenlander of the Joint Highway Research Project for his review of the manuscript; and to Professor L. J. Cote, Department of Mathematics and Statistics, for his advice on the statistical analyses and for his review of the manuscript.

Acknowledgment is also given to the Indiana State Police, Accident Records Division; the Indiana State Highway Commission, Division of Planning and the Division of Traffic Engineering; and to the traffic or police departments of the cities in which the intersections were located for making the data used in this research available to the author.

Acknowledgment is also given to Darrell A. Wright and Walter C. Vodrazka for their assistance in parts of the analyses.

TABLE OF CONTENTS

	Page
LIST OF TABLES	v
LIST OF FIGURES	viii
ABSTRACT	xi
INTRODUCTION	1
PURPOSE AND SCOPE	4
PREVIOUS INVESTIGATIONS	6
PROCEDURE	14
Selection of Intersections	14
Collection of Volume Data	16
Collection of Accident Data	17
ANALYSES AND RESULTS	23
Statement of Hypothesis	23
Comparison of Accident Occurrence	25
Comparison of Accident Severity	35
Comparison of Accidents During Daylight	61
Comparison of Accidents on Dry Pavement	65
Changes in Accidents During Each Hour of Day, Day of Week, and Month of Year	67
Changes in Accident Rates Correlated with Speed	74
Changes in Accidents Correlated with Pretimed Signal Warrants	76
Accidents Per Year Correlated with Traffic Volumes	82
Comparison to Solomon's Procedure	83
Comparison to Syrek's Procedure	88
Comparison to Webb's Procedure	90
SUMMARY OF RESULTS	94
CONCLUSIONS	98

TABLE OF CONTENTS (continued)

	Page
BIBLIOGRAPHY	100
APPENDIX A: WARRANTS FOR PRETIMED SIGNALS	102
APPENDIX B: DATA	108
Part I: Intersection Locations	108
Part II: Intersection Traffic Data	111
Part III: Intersection Accident Data	114
APPENDIX C: TRAFFIC VOLUME CALCULATIONS	135
APPENDIX D: CURVES FOR DETERMINING WHETHER A SIGNIFICANT CHANGE IN ACCIDENTS OCCURRED AFTER A ROADWAY MODIFICATION USING PROCEDURE 1	138
APPENDIX E: COMPARISON OF TWO POISSON DISTRIBUTED OBSERVATIONS USING PROCEDURE 2	144
APPENDIX F: COLLISION DIAGRAMS FOR SELECTED INTERSECTIONS	148

LIST OF TABLES

Table	Page
1. Average Accident Rates for Syrek's Traffic Volume Groupings	10
2. Percentage of Intersections having an Absolute Change in the Indicated Accident Pattern after Signalization	27
3. Percentage of the Thirty-two Two-way Stop Controlled Intersections having a Significant Change in the Indicated Accident Pattern after Signalization	29
4. Percentage of the Six Four-way Stop Controlled Intersections having a Significant Change in the Indicated Accident Pattern after Signalization	30
5. Percentage of Intersections having a Significant Decrease in Accidents after Signalization	34
6. Percentage of the Thirty-two Two-way Stop Controlled Intersections having a Significant Change in the Numbers of Injury Accidents after Signalization	37
7. Percentage of the Six Four-way Stop Controlled Intersections having a Significant Change in the Numbers of Injury Accidents after Signalization	38
8. Percentage of the Thirty-two Two-way Stop Controlled Intersections having a Significant Change in the Numbers of Injury and Non-injury Accidents after Signalization (Procedure 1)	40

LIST OF TABLES (continued)

Table	Page
9. Percentage of the Thirty-two Two-way Stop Controlled Intersections having a Significant Change in the Numbers of Injury and Non-injury Accidents after Signalization (Procedure 2)	41
10. Percentage of the Six Four-way Stop Controlled Intersections having a Significant Change in the Numbers of Injury and Non-injury Accidents after Signalization (Procedure 1)	42
11. Percentage of the Six Four-way Stop Controlled Intersections having a Significant Change in the Numbers of Injury and Non-injury Accidents after Signalization (Procedure 2)	43
12. Percentage of Intersections having an Increase in the Total Property Damage Costs	45
13. Numbers of Accidents	48
14. Numbers of Fatal and Injury Accidents	49
15. Percentage of Accidents that were Fatal or Injury Accidents	50
16. Percentage of the Thirty-two Two-way Stop Controlled Intersections having a Significant Change in the Numbers of Accidents During Daylight and Dark Hours after Signalization (Procedure 1)	62
17. Percentage of the Thirty-two Two-way Stop Controlled Intersections having a Significant Change in the Numbers of Accidents During Daylight and Dark Hours after Signalization (Procedure 2)	63
18. Percentages of Accidents During Daylight Hours	64
19. Percentages of Accidents on Dry Pavement	66
20. Summary of Solomon's Data Adjusted for the Traffic Growth	86
21. Summary of Study Data for Comparison to Solomon's Data	87

LIST OF TABLES (continued)

Table	Page
22. Average Accident Rates with Intersections Grouped According to Syrek's Volume Grouping	91
23. Minimum Vehicular Volumes for Warrant 1	103
24. Minimum Vehicular Volumes for Warrant 2	105
25. Intersection Locations	109
26. Intersection Traffic Data	112
27. Intersection Accident Data	116

LIST OF FIGURES

Figure	Page
1. Locations of Study Intersections	5
2. Groupings of Intersections with Respect to Major and Minor Street Volumes	8
3. Average Number of Accidents per Year Related to Traffic Volume at Semi-Urban Type Signalized Intersections	13
4. Investigating Officers Accident Report Form, Side One	18
5. Investigating Officers Accident Report Form, Side Two	19
6. Form Used to Record Accident Data	21
7. Variation in Property Damage Cost of Total Accidents	53
8. Variation in Property Damage Cost of Right-angle Accidents	54
9. Variation in the Property Damage Cost of Rear-end Accidents	55
10. Variation in the Property Damage Cost of Miscellaneous Accidents	56
11. Variation in the Property Damage Cost of Total Accidents	57
12. Variation in the Property Damage Cost of Right-angle Accidents	58
13. Variation in the Property Damage Cost of Rear-end Accidents	59
14. Variation in the Property Damage Cost of Miscellaneous Accidents	60

LIST OF FIGURES (continued)

Figure	Page
15. Hourly Variations of Traffic Accidents and Volume	68
16. Hourly Variations of the Relative Accident Rate	69
17. Daily Variations of Traffic Accidents and Volume	70
18. Daily Variations of the Relative Accident Rate	71
19. Monthly Variations of Traffic Accidents and Volume	72
20. Monthly Variations of the Relative Accident Rate	73
21. Average Sum of the Speed Limits of the Intersecting Roads Versus the Average Accident Rate for the Intersections	75
22. Changes in Accidents Correlated with Traffic Volume and Pretimed Signal Warrants (Group 1- Intersections which Meet the Warrants)	77
23. Changes in Accidents Correlated with Traffic Volume and Pretimed Signal Warrants (Group 2- Intersections which Did not Meet Warrants)	78
24. Changes in Accidents Correlated with Traffic Volume and Pretimed Signal Warrants (Group 3- Intersections which had Five or More Right-angle Accidents in the Preceding Twelve Months	79
25. Accident Rates Correlated to Major and Minor Street Traffic Volumes	84
26. Placement of Intersections with Respect to Syrek's Groupings	89
27. Placement of Intersections on Graph of Webb's Semi-Urban Model	93
28. Values of Accidents Needed to Occur After a Modification to Experience a Significant Change in Accidents (Significance Level:1%)	140

LIST OF FIGURES (continued)

Figure	Page
29. Values of Accidents Needed to Occur After a Modification to Experience a Significant Change in Accidents (Significance Level:10%) . .	141
30. Values of Accidents Needed to Occur After a Modification to Experience a Significant Change in Accidents (Significance Level:15%) . . .	142
31. Values of Accidents Needed to Occur After a Modification to Experience a Significant Change in Accidents (Significance Level:30%) . . .	143
32. Collision Diagram for SR 66 & New Green River Road (Intersection 2)	149
33. Collision Diagram for US 52 By-Pass & Salisbury Street (Intersection 6)	150
34. Collision Diagram for US 20 & Twyckenham Drive (Intersection 7)	151
35. Collision Diagram for SR 49 & Evans Avenue (Intersection 16)	152
36. Collision Diagram for SR 67 & Brown Road (Intersection 32)	153

ABSTRACT

Schoene, George William. M.S.C.E., Purdue University, June 1966. Effects of A Change in the Control Device on Intersection Accidents. Major Professor: Harold L. Michael.

The demands by the motoring public for relief from traffic congestion are being satisfied by the construction of new facilities and by the improvement of old facilities. One traffic control device that has been employed to provide relief from such congestion is the traffic signal.

Because of the traffic signal being used successfully to relieve congestion at intersections, it has been adopted by many of the motoring public as the cure-all for intersection problems -- especially accidents. This assumption is annually demonstrated by the large number of requests that are received by all highway organizations for the installation of traffic signals at locations where one or several recent traffic accidents have occurred.

The purpose of this research was to determine what changes occur in the pattern of intersection accidents when two-way or four-way stops are replaced by traffic signals.

To accomplish this aim, data were collected for all traffic accidents which occurred for a period of about two years before and an equal time period after the installation of the traffic signals at thirty-eight intersections. The

pattern and volume changes in the accidents were compared and analyzed on an intersection basis so that differences in the accident producing characteristics between intersections would not confound the effects of the changes in the control devices.

It was found that the installation of traffic signals at an intersection under current practices in Indiana did not usually result in fewer accidents occurring at that intersection. In fact, a large proportion of the intersections did not have a change in the numbers of accidents that was great enough to be considered statistically significant. For those intersections which did have a change in the numbers of the various accident types large enough to be considered significant; the trend was an increase in total, rear-end and miscellaneous accidents and a decrease in right-angle accidents.

The change in the composition of the total number of accidents was very definite. Right-angle accidents normally decreased, while rear-end accidents increased. The remaining or miscellaneous accidents increased more often than decreased. An increase in rear-end accidents often overshadowed the decrease in right-angle accidents and an increase in total accidents often occurred. On the other hand, when there were five or more right-angle accidents per year prior to signalization, the increase in rear-end accidents was not usually large enough to balance the decrease in right-angle accidents and a decrease in total accidents occurred.

The severity of the overall accident condition did not change at most intersections as most intersections had no significant change in the number of total accidents, the number of accidents which were injury and the amount of the property damage cost. When there was a significant change in these accident characteristics, the trend was an increase.

INTRODUCTION

The heavy growth of motor vehicle usage since 1945 has placed a tremendous stress on the highway system of this nation. The resulting demands by the motoring public for relief from traffic congestion are being satisfied by the construction of new facilities and by the improvement of old facilities, but many problems of traffic conflict continue to be present.

Wherever two or more traffic streams cross or meet, thereby forming an intersection, a major congestion or conflict point develops. At such conflict points there is always a possibility of collision between vehicles, and as traffic volumes increase, the probability of an accident occurring also increases.

To improve the flow of traffic on the present highway system, numerous traffic control devices have been employed at these points of congestion and conflict by highway engineers and others. The control devices usually employed at intersections are stop or yield signs, or traffic signals depending upon the physical and traffic characteristics of each intersection. Even though the use of control devices may improve the flow of traffic by minimizing the effects of congestion and conflict, accidents still occur. In fact, it has been observed by many that the number of accidents often

increases after the installation of some control devices.

The warrants for the installation of control devices at intersections as developed by the traffic and highway engineering profession usually consist of measures of the volumes of traffic and recent accident experience (see Appendix A). Although the results of considerable research were the basis for these warrants, many intersection control devices are demanded by the public following one or two accidents. As a result, traffic engineers have often been required to install unwarranted control devices.

Many motorists consider the traffic signal to be a cure-all for intersection problems, especially accidents. Most frequently the demand for a signal installation is highly emotional on the part of the public, resulting from the shock of one or two past accidents or the fear of future accidents.

The recurrence and the pressure of such demands for unwarranted traffic signals prompted a member of the staff of the Division of Traffic Engineering of the Indiana State Highway Commission to suggest this research in Indiana. The suggestion was made with the hope that factual data on accident experience following the installation of traffic signals could be developed.

In Indiana in 1963 there were 144,818 reported traffic accidents of which slightly over 41 percent occurred at intersections, even though their area is only a small percentage of

the total area of the road system in Indiana (6)¹. In 1964, 41 percent of all accidents again occurred at intersections (7).

The high percentage of accidents occurring at intersections and the almost continuous demands for control devices of higher order at these intersections make it certainly desirable for engineers to understand the correlation between intersection accidents and the control device employed.

¹ The numbers in parentheses refer to numbers in the Bibliography.

PURPOSE AND SCOPE

It was the purpose of this research to provide information on the effects of changes in intersection control devices on the various types of intersection accidents. The main concern of this research was the change in intersection accidents which could be expected if a traffic signal replaced two-way stops.

The thirty-eight intersections used in this research are located in many regions of Indiana (see Figure 1). Thirty-one of the intersections are part of the State Highway System. The remaining seven intersections are part of the major street systems of the cities of Fort Wayne, Indianapolis or Kokomo. The intersections are located predominantly in rural or suburban areas. Those four intersections which are not, are located in each of the urban areas of Albany, Corydon, Monon, and Rockport. The major street of these four intersections is the main highway through the town.

FIGURE 1. LOCATIONS OF STUDY INTERSECTIONS

PREVIOUS INVESTIGATIONS

A review of the literature disclosed several studies in recent years related to the topic of this research. One of these, by J. Carl McMonagle, who made a before and after signalization study of intersections on Michigan rural highways in the early 1950's (10), resulted in the following findings:

1. On one particular suburban trunkline "70 percent of all accidents occurred on the 30 percent of the route that was part of the intersection areas".
2. The traffic signal is a regulator valve for traffic flow; it is not the panacea for all intersection problems.
3. Mass grouping of traffic accidents from many locations means little or nothing when considering traffic signal problems.
4. Rural trunkline intersections might need specially designed signal equipment because of their special problems -- high speeds and volumes, roadside cluster developments, and isolated locations.
5. Accident patterns changed after signalization, rear-end collisions increased greatly while right-angle collisions decreased some.

David Solomon reported the findings of a before and after signalization study conducted in Michigan for the years 1946 to 1957 (16). The study was made using intersections located in rural, suburban and urban areas. For the thirty-nine signalized intersections it was found that the simpler the geometrics of the intersection, the greater the increase in accidents after signalization.

Solomon grouped the data from the intersections when comparing the changes in the characteristics of accidents. After signalization of the intersections, it was found:

1. The number of injuries decreased by twenty percent.
2. The percentage of accidents that occurred during inclement weather increased from 16 to 24 percent.
3. The percentage of accidents that occurred during daylight hours increased from 59 to 63 percent.
4. The total accidents increased 23 percent, right-angle accidents decreased 51 percent, rear-end accidents increased 200 percent, and miscellaneous accidents increased 43 percent.

In the early 1950's David Syrek conducted research for the Los Angeles County, California, Road Department to construct a model by which average accident rates could be predicted at four-way approach intersections (17). The 420 intersections were grouped according to control device and entering average daily traffic volumes on the major and minor streets (See Figure 2).

FIGURE 2. GROUPINGS OF INTERSECTIONS WITH RESPECT TO
 MAJOR AND MINOR STREET VOLUMES
 (SOURCE: DANIEL SYREK, "ACCIDENT RATES AT INTERSECTIONS,"
TRAFFIC ENGINEERING, MAY, 1955.)

From the nearly 2500 accidents that occurred at these intersections average accident rates were calculated for each volume grouping (see Table 1).

The following trends were observed for the average accident rates of all accidents:

1. "The accident rates for all three control types increased as the minor street volume increased."
2. "The accident rate for four-way stops increased markedly when the major street volume was greater than 12000 ADT."
3. "The accident rate at two-way stops showed a reverse trend of decreasing rate with increasing major street volume."
4. "Determination of empirical rates of vehicle accidents at intersections shows them to be influenced in varying degrees by major and minor street volume and control type."
5. "Use of such rates enables predictions with considerable accuracy regarding: a. Direction of individual rate change. b. Total amount of change at a sufficient sample of intersections."
6. "Use of such rates enables predictions with lesser accuracy of: a. Total change at individual intersections. b. Changes in collision type component rates at individual intersections."
7. "Use of such rates helps in understanding average effects of control change."

Table 1. Average Accident Rates¹ for Syrek's Traffic Volume Groupings².

Volume Grouping	Total Accidents	Right- angle	Rear- end	Left- turn	Fatality	Injury	Property Damage
--------------------	--------------------	-----------------	--------------	---------------	----------	--------	--------------------

Two-way Stop Intersections

A	.72 ¹	.60	.07	.05	.05	.29	.38
B	.49	.41	.06	.02	.03	.15	.31
C	.26	.17	.05	.04	--	.11	.15
D	.14	.09	.02	.03	.01	.03	.10
E	.08	.02	.03	.03	.01	.03	.04

Four-way Stop Intersections

F	.85 ¹	.44	.34	.07	.09	.28	.48
G	.78	.52	.23	.03	.02	.21	.55
H	.56	.35	.14	.07	.01	.09	.46
I	.47	.32	.13	.02	.02	.15	.30
J	.42	.23	.15	.04	.02	.10	.30
K	.14	.06	.06	.02	.01	.05	.08

Signalized Intersections

L	.86 ¹	.29	.20	.37	.06	.26	.54
M	.80	.34	.19	.27	.04	.25	.51
N	.77	.31	.19	.27	.04	.25	.48
O	.66	.30	.19	.17	.05	.21	.40
P	.45	.27	.10	.08	.03	.14	.28
Q	.36	.10	.21	.05	.02	.09	.25
R	.21	.05	.21	.04	--	.08	.13

¹ Accidents per million entering vehicles.

² Source: Daniel Syrek, "Accident Rates at Intersections," Traffic Engineering, May, 1955.

Syrek's approach for comparing accidents before and predicted accidents after signalization was to develop average accident rates for various volume groupings which could be compared to the present accident rate of an intersection for which a control device change was being contemplated. If the present accident rate of the intersection in question was lower than the average rate developed, then an increase in the accident rate could be expected after signalization. Syrek felt that component rates could be used also but he did not believe that component rates were as accurate for predicting purposes as the total accident rate.

In the early 1950's George M. Webb conducted research to develop a model by which the average number of accidents per year could be predicted at two phase signalized intersections (20). Using 97 signalized intersections with four approaches and on the California Rural State Highway System in unincorporated areas; he found that there was a relationship between the average number of accidents per year and a function of the product of the average daily traffic flows on each of the intersecting roads.

Since the approach speed on the major road could not be controlled, the intersections were divided into three groups: Urban-those with speeds of 25 mph or less, Semi-Urban-those with speed greater than 25 mph but less than 45 mph and Rural-those speeds over 45 mph.

For these three groups of intersections, the following mathematical model was developed to predict the average number of accidents per year based upon the intersecting traffic volumes:

$$N = m x^a y^b$$

N: Average number of accidents per year.

x: 1/100 of the average daily traffic on the State Highway.

y: 1/100 of the average daily traffic on the cross road.

	Urban	Semi-Urban	Rural
m:	0.03	0.17	0.28
a:	0.55	0.45	0.51
b:	0.55	0.38	0.29

This mathematical model was also placed in chart form as it is for the Semi-Urban grouping in Figure 3.

FIGURE 3. AVERAGE NUMBER OF ACCIDENTS PER YEAR RELATED TO TRAFFIC VOLUME AT SEMI-URBAN TYPE SIGNALIZED INTERSECTIONS
(SOURCE: GEORGE M. WEBB, "THE RELATION BETWEEN ACCIDENTS AND TRAFFIC VOLUMES AT SIGNALIZED INTERSECTIONS," INSTITUTE OF TRAFFIC ENGINEERS PROCEEDINGS, 1955.)

PROCEDURE

The before and after study technique was chosen as the method to be used for this research. It was, therefore, necessary to select signalized intersections for which good historical accident data were available, to collect intersection physical and traffic data for both the before and after periods, to collect pertinent information about the accidents occurring at each intersection for a period of time both before and after the installation of a signal, and then to compare and analyze the characteristics of the before signalization accidents with the characteristics of the after signalization accidents.

Selection of Intersections

In selecting the intersections to be used in this research, a sample of intersections was desired which were similar for some design and location characteristics so as to minimize accident causation variables between intersections. A set of criteria was developed to be used when selecting the intersections. These criteria were,

1. Accident histories for each intersection must be available for approximately two years both before and after the date of signal installation.

2. There should not be another control device or rail-road crossing within two blocks of the study intersection.
3. There should not have been any major construction at the intersection from the beginning to the end of the study.
4. The intersection must have four approaches, the opposing approaches not being offset, and the angle between the approaches should be 90 degrees.
5. The driver vision of the control device should not be obstructed.
6. The intersection should not be on or near a significant verticle or horizontal curve.

From the list of locations of signalized intersections on the state highway system, provided by the Division of Traffic Engineering of the Indiana State Highway Commission, thirty-one intersections were selected. In addition, seven intersections were chosen from the street systems of the cities of Fort Wayne, Indianapolis, and Kokomo. For the exact locations of these intersections, see Appendix B.

The intersections predominantly are in rural and suburban areas. However, four intersections were located in each of the urban areas of Albany, Corydon, Monon, and Rockport. The major street of these four intersections is the main highway through the town.

As each intersection was selected a sketch of the physical characteristics of the intersection was made. This sketch was used when comparing intersections and when attempting to assign a cause to miscellaneous accidents.

Collection of Volume Data

Almost all accident studies indicate that traffic volume and accidents are correlated. In this study traffic volume and the control device are the only characteristics of the intersection assumed to have changed during the study period.

Because the signal installations were made several years, 1956 thru 1963, prior to this study, it was not possible to take counts of the traffic volume using the intersections at the times of signalization. Turning movement counts that were made prior to signal installations; twenty-four hour counts of the traffic volumes on major roads throughout the state; and monthly, weekday, and area factors that are used to convert twenty-four hour weekday counts into average daily traffic (ADT) counts were obtained from the Division of Planning and the Division of Traffic Engineering of the Indiana State Highway Commission or the cities in which the intersections were located. This traffic volume information was used to develop an estimate of the traffic using each intersection during the before and after signalization periods by a method described in Appendix C.

The ADT entering the intersections on the major and minor streets ranged from 3000 to 21,000 vehicles and from 700 to 6300 vehicles, respectively, when the intersections were signalized. The sum of these two volumes averaged for all intersections was 13,100 vehicles per day. These volumes are given for each intersection in Appendix B.

The traffic growth rates for the intersections during the study ranged from 0.2 to 12.5 percent per year.

Collection of Accident Data

The files of the reports of traffic accidents maintained by the Indiana State Police served as the primary source of accident data. Indiana law requires that all accidents involving \$50 or more property damage, a personal injury, or a death be reported to the State Police. Copies of these accident reports are on file for the years of 1956 to the present in the Accident Records Division of the Indiana State Police. Other sources of accident data were the local police and traffic departments of the cities in which the intersections were located. The form used by the officer when investigating an accident is shown in Figures 4 and 5.

Accident data were collected from the accident reports on all accidents which occurred on each intersection approach within 200 feet of the intersection (14). Such data was obtained for a period of approximately twenty-four months before the signal installation and for an equal time period after signalization. The form used to record this data is

Mail Report To: INDIANA STATE POLICE, INDIANAPOLIS 4, INDIANA

DO NOT WRITE IN THIS SPACE (12-13-14-15)		(16)	(13-3-4-5-6-7)
(8) TYPE	(9) SOURCE	(10-11) ANALYSIS	(12) LOSS
		LOCATION	ACCIDENT NO.

TIME	(17-18)	(19-20)	(21)	(22)	(23-24)
	DATE OF ACCIDENT		DAY OF WEEK		TIME OF DAY
	Month	Day	Year		AM
					PM

LOCATION	(25-26)	(27)	(28-29)	(30-31)
	PLACE WHERE ACCIDENT OCCURRED: If accident occurred outside of city limits, indicate distance from nearest city or town limits, using two directions, if necessary. _____. Occurred within corporate limits. _____. Occurred outside corporate limits.		COUNTY _____ CITY OR TOWN _____	
	TOWNSHIP _____		LIMITS OF _____	
	(32-33-34)		(35-36) _____ City or Town _____	
	ROAD ON WHICH ACCIDENT OCCURRED _____		AT IT'S INTERSECTION WITH _____	
Name of Street or No. of Highway (US or STATE). If no No., use name. Name or Number of Intersecting Street or Highway.				
IF NOT AT INTERSECTION _____ FEET (_____ N _____ S _____ E _____ W) OF _____				
Show nearest intersection, house number, or other identifying landmark.				

VEHICLE INFORMATION	VEHICLE NUMBER 1: (41) _____ (42-43) _____	VEHICLE NUMBER 2: (41) _____ (42-43) _____	
	YEAR _____ MAKE _____ TYPE _____	YEAR _____ MAKE _____ TYPE _____	
	Sedan, Truck, Bus, etc. (44) _____		
	LICENSE PLATE _____	LICENSE PLATE _____	
	DRIVER (Print) Last Name _____ First _____ Middle _____	DRIVER (Print) Last Name _____ First _____ Middle _____	
	ADDRESS (Print) _____	ADDRESS (Print) _____	
	BIRTH DATE _____ AGE _____ SEX _____	BIRTH DATE _____ AGE _____ SEX _____	
	City and State _____	City and State _____	
	DRIVER'S LICENSE _____	DRIVER'S LICENSE _____	
	Number _____ State _____ Type _____ (49) _____	Number _____ State _____ Type _____ (49) _____	
OWNER _____	OWNER _____		
Last Name _____ First _____ Middle _____	Last Name _____ First _____ Middle _____		
ADDRESS _____	ADDRESS _____		
Street or R.F.D. _____ City _____ State _____	Street or R.F.D. _____ City _____ State _____		
PARTS OF VEHICLE DAMAGED _____	PARTS OF VEHICLE DAMAGED _____		
ESTIMATE OF REPAIR \$ _____	ESTIMATE OF REPAIR \$ _____		
VEHICLE REMOVED TO _____ BY _____	VEHICLE REMOVED TO _____ BY _____		
(53-54) (55) _____	(53-54) (55) _____		
NAME (Print) Last Name _____ First _____ Middle _____	NAME (Print) Last Name _____ First _____ Middle _____		
AGE _____ SEX _____	AGE _____ SEX _____		
ADDRESS (56) _____	ADDRESS (56) _____		
Street or R.F.D. _____ City _____ State _____	Street or R.F.D. _____ City _____ State _____		
DRIVER _____ PASSENGER _____ IN VEHICLE NUMBER _____	DRIVER _____ PASSENGER _____ IN VEHICLE NUMBER _____		
PEDESTRIAN _____ Other (EXPLAIN) _____	PEDESTRIAN _____ Other (EXPLAIN) _____		
NATURE AND EXTENT OF INJURIES _____	NATURE AND EXTENT OF INJURIES _____		
Total Number Killed (50) _____			
Injured (51) _____ (52) _____			
Mark First One That Applies (58)			
1 _____	2 _____	3 _____	4 _____
Died as result of accident.	Visible signs of injury, as bleeding wound, distorted limb or head to be carried away.	Other visible injuries, as bruises, swelling, abrasions, limping, etc.	No visible injuries, but complaint of pain or momentary unconsciousness.

DAMAGE TO OTHER PROPERTY _____	Owner's Name and Address _____	Nature of Damage _____	ESTIMATE OF REPAIR \$ _____
Name of Object (s) _____			

This form is approved by the Superintendent, Indiana State Police, pursuant to Burns Indiana Statutes 47-1918, Acts 1939, Ch. 48.

FIGURE 4. INVESTIGATING OFFICERS ACCIDENT REPORT FORM, SIDE ONE

<p>(58) CHEMICAL TEST Driver 1 2 Ped. (Check one)</p> <p>0. No test offered. 1. Test offered but refused 2. Breath test given. 3. Blood test given. 4. Urine test given.</p> <p>(60) ARREST—(Check one) Driver 1 2 Ped.</p> <p>0. Not arrested 1. Arrested for O. U. I. 2. Arrested for other violation.</p> <p>(61) SPEED LIMIT MPH (62) SPEED BEFORE ACCIDENT MPH</p> <p>Veh. 1. MPH Veh. 2. MPH</p> <p>(63) CONTRIBUTING CIRCUMSTANCES INDICATED Driver 1 2 Ped.</p> <p>1. Speed too fast. 2. Failed to yield right-of-way 3. Drove left of center. 4. Improper overtaking. 5. Passed stop sign. 6. Disregarded traffic signal. 7. Followed too closely. 8. Made improper turn. 9. Other improper driving. 10. Inadequate brakes. 11. Improper lights. 12. Had been drinking.</p> <p>(64) VEHICLE DEFECTS Driver 1 2 Ped.</p> <p>0. No defects. 1. Brakes defective. 2. Lights defective 3. Defective steering 4. Puncture or blowout. 8. Other defects.</p> <p>(65) VISION OBSCURED Driver 1 2 Ped.</p> <p>0. Not obscured. 1. By building/s. 2. By embankment. 3. By signboard. 4. Trees, crops, etc. 5. By hillcrest. 8. (Specify other)</p>	<p style="text-align: center;">INDICATE ON THIS DIAGRAM WHAT HAPPENED</p> <p style="text-align: right;">DRAW DIAGRAM TO SCALE</p> <p style="text-align: right;">Indicate North by arrow </p> <p>DESCRIBE WHAT HAPPENED: Refer to vehicle by number.</p> <p>WHAT DRIVERS WERE GOING TO DO BEFORE ACCIDENT: (Check applicable items for each driver.) Driver No. 1 was headed N S E W on (Name or number of street or highway.) Driver No. 2 was headed N S E W on (Name or number of street or highway.) (Specify other)</p> <p>WHAT PEDESTRIAN WAS DOING BEFORE ACCIDENT (87) Pedestrian was going N S E W along Street or Highway From (N E corner to S. E. corner or from West side to East side, etc.) (Check one) 0. Not in roadway. 1. Walking in roadway with traffic. 2. Walking in roadway against traffic. 3. Pushing or working on vehicle. 4. Getting on or off vehicle. 5. Standing in roadway.</p> <p>CONDITION OF DRIVERS AND PEDESTRIANS (Check one) (68) (69) Driver 1 2 Ped. 0. Had NOT been drinking. 1. Obviously drunk. 2. Ability impaired. 3. Ability not impaired. 4. Unknown if impaired. (70) (71) 11. Apparently normal. 12. Eyesight defective. 1. Hearing defective. 2. Other defects. 3. Illness. 4. Fatigued. 5. Apparently asleep. 6. Attention diverted. 7. Advanced senility. 8. Other handicaps. (Specify other handicaps)</p>
<p>(72) TRAFFIC CONTROL Driver 1 2 Ped.</p> <p>0. Police officer. 1. Automatic signal. 2. Yield right-of-way sign. 3. Center line marked. 4. Other lane markings. 5. Stop sign. 6. Warning sign or signal. 7. No passing zone. 8. All others.</p>	<p>(73) CHARACTER (Check two) 1. Straight 2. Curve 3. Level 4. On grade 5. Hillcrest.</p> <p>(74) SURFACE (Check one) 1. Concrete. 2. Blacktop. 3. Sand or dirt. 4. Gravel. 5. Other</p> <p>(75) CONDITION (Check one) 1. Dry. 2. Wet. 3. Snow/ice 4. Other</p> <p>(76) WEATHER (Check one) 1. Clear. 2. Rain. 3. Snowing. 4. Fog 5. Other</p> <p>(77) LIGHT (Check one) 1. Daylight. 2. Dark. 3. Dawn or dusk.</p> <p>(78) KIND OF LOCALITY (Check one to show that area adjacent to roadway for 300' was primarily.) 1. School or playground. 2. Industrial or business. 3. Residential. 4. Open country.</p>
<p>(80) ROAD DEFECTS</p> <p>1. Foreign material on surface. 2. Loose sand, gravel, etc. 3. Holes, ruts, dips, bumps, etc. 4. Defective shoulders. 5. Obstruction not lighted or signaled. 6. Standing water, landslide, etc. 7. Obstructed by previous acc. 8. All other defects.</p>	<p>WITNESSES Name Address Location Name Address Location</p> <p>POLICE ACTION Name Charge Name Charge</p> <p>INVESTIGATION: Time notified of accident AM PM Time of arrival at scene AM PM Where else was investigation made? Is investigation complete? Yes No Were photographs taken? Yes No Driver report form furnished to driver No. 1 driver No. 2 Department Date of report</p> <p>*SIGNATURE ARD-2 Investigator's Report Rev. 80</p>

FIGURE 5. INVESTIGATING OFFICERS ACCIDENT REPORT FORM, SIDE TWO

shown in Figure 6. The choice of twenty-four months for the before and after signalization time periods was a compromise between having insufficient data if a shorter period of time were used, and having increased expense or fewer intersections available for study if a longer period of time were used. The before and after time periods ranged from thirty-one to fifteen months, with most intersections having exactly twenty-four month time periods.

Not only was the change in the total number of accidents to be investigated but also the change in the various types of accidents. Originally it was planned to analyze the following types of accidents: right-angle, rear-end, left-turning, side-swipe and the remaining, classified as "other". A left-turning accident, however, might be also classified as a head-on collision as the two vehicles often meet nearly head-on. A side-swipe accident at an intersection is usually a collision between a vehicle passing a right turning vehicle on the right.

After examining these accident types for both the before and after periods for all of the intersections, it was decided to classify only the right-angle and rear-end accident types. The remaining accidents were reclassified as "miscellaneous". This was done because the remaining accidents were infrequent.

Since traffic volumes increased during the study periods, some adjustment to the numbers of accidents occurring before signalization was made in order to compare such numbers with

City _____

Weather:

Pavement:

Clear _____

Dry _____

Accident No. _____

Rain _____

Wet _____

Snow _____

Snow/ice _____

Date _____

Fog _____

Cloudy _____

Day _____ Time _____ AM

Accident occurred on _____

At intersection with _____

Or _____ feet N S E W of _____

Injury or Fatality: (I or F)

Property damage

Repair
Estimate

Vehicle

1

2

3

Driver _____

Objects _____

Veh 1 _____

Passenger 1 _____

Veh 2 _____

2

Veh 3 _____

Pedestrian _____

Statement and diagram of
accident:

Before accident Vehicle

1

2

3

Direction _____

on _____

Passing _____

Turn Rt _____

Turn Lt _____

U Turn _____

Backing _____

Slow/stop _____

St. ahead _____

Start in lane _____

Start fm park _____

Avoid V.O.P. _____

Skid b brakes _____

Skid a brakes _____

Parked _____

Other _____

FIGURE 6. FORM USED TO RECORD ACCIDENT DATA

those occurring after signalization. The method used for this adjustment was to multiply the number of accidents occurring during the before period by the intersection ratio of the total volume of traffic entering the intersection during the after period to the total volume of traffic entering the intersection during the before period. This adjusted number of before accidents was used for all before and after signalization accident comparisons. The after to before entering volume ratio was used because no better accident-volume relationship could be determined and it was simple and logical.

ANALYSES AND RESULTS

Statement of the Hypothesis

The patterns and characteristics of accidents occurring at two-way and four-way stop controlled intersections were compared and analyzed to the patterns and characteristics of accidents occurring at the same intersections after the stop signs were replaced with traffic signals. This analysis was done on an individual intersection basis unless specifically noted. This analysis was designed to determine the possible changes in the accident characteristics which would be due to the signal installation. If the data of the intersections were grouped, a very large decrease in an accident characteristic at one intersection could overshadow smaller but significant increases in that same characteristic at several intersections. The two sources of randomness in the data are, therefore, the randomness in the occurrences of accidents at a particular intersection and the randomness in the selection of the intersections used in this study.

For each intersection having an absolute change in an accident pattern or characteristic, it was necessary to establish a hypothesis testing procedure to decide if this absolute change were great enough to be considered significant and due to the signal installation or insignificant and due

merely to chance. The hypothesis tested was that the accident parameter had the same value in both the before signalization period and in the after signalization period.

Two procedures were used to test this hypothesis. Procedure 1 used the before signalization estimate as though it were a constant value. This is justified when the estimate is based upon a long period of time. Procedure 2 regarded both estimates as being random. Procedure 1 has been used in recent highway accident research (16). Procedure 2 is a statistical technique which is relatively new in its application to highway research and can be useful in the evaluation of before and after data. Both procedures give substantially the same results when viewed qualitatively. Results using both procedures are, therefore, presented -- procedure 1 because it has been used in past research and procedure 2 because it is more realistic statistically.

The significance levels or levels of observation used in this research were chosen arbitrarily. Not only do they represent the probability of rejecting a true hypothesis, as usual, but they are also "levels of observation" from which the trends of the changes in accident characteristics may be noted. The significance level was chosen as 10 percent for procedure 2. For procedure 1 the one percent level gave similar results. The difference in significance levels -- one and ten percent -- for the two procedures for obtaining comparable results is due to the fact that the assumptions for

procedure 1 are not as well based on the actual conditions as for procedure 2.

The tests of hypothesis were also performed for both procedures using larger significance levels or levels of observation so that more intersections would have significant changes. These significance levels made the directions of the changes of the accident characteristics more evident. These new significance levels or levels of observation were 30 and 50 percent for procedures 1 and 2, respectively.

Hereafter, these four significance levels - 1, 30, 10, and 50 percent -- will be referred to as levels of observation and designated as A, B, C, and D. This notation was used to avoid misinterpretation of the tables summarizing the tests of hypothesis performed on an intersectional basis. These tables indicate the percentages of intersections having a significant increase, significant decrease, or no significant change in an accident characteristic from before to after signalization.

Comparison of Accident Occurrence

Of concern was the number of accidents occurring in equal time periods before and after signalization. Therefore, a comparison was made between the adjusted numbers of before accidents and the numbers of after accidents. This comparison was made for the total number of accidents, the right-angle accidents, the rear-end accidents, and the remaining or miscellaneous accidents.

As was expected, very few intersections experienced no change in the absolute numbers of accidents. This finding was true for the total accidents as well as the specific types of accidents (see Table 2).

Because almost all intersections had a change in the absolute numbers of accidents from before to after, it was necessary to determine if this absolute difference in the numbers of accidents were greater than that expected by chance alone. To make this determination it was necessary to test the hypothesis that the numbers of accidents were statistically identical. Both procedures 1 and 2 were used to evaluate the test.

For both procedures it was assumed that accident occurrence has a Poisson distribution. The test of hypothesis was that the mean of the Poisson distribution is the same after signalization as before. For procedure 1, described in Appendix D, it was assumed that the number of adjusted before period accidents was a constant value. The number of after accidents was then compared to this constant value. For procedure 2, described in Appendix E, the number of adjusted before accidents was compared with the number of after accidents taking into account the fact that both are random.

Two questions were implied when evaluating this hypothesis:

1. Was there a significant change in the numbers of accidents?

Table 2. Percentage of Intersections having an Absolute Change in the Indicated Accident Pattern after Signalization.

	<u>Two-way Stops</u> ¹	<u>Four-way Stops</u> ²
<u>Total Accidents</u>		
Increase	53	17
No Change	3	17
Decrease	44	66
<u>Right-angle Accidents</u>		
Increase	31	17
No Change	3	0
Decrease	66	83
<u>Rear-end Accidents</u>		
Increase	78	83
No Change	19	17
Decrease	3	0
<u>Miscellaneous Accidents</u>		
Increase	50	33
No Change	28	33
Decrease	22	33

¹ Thirty-two two-way stop intersections.

² Six four-way stop intersections.

2. Was there a significant decrease in the numbers of accidents?

The first question assumed that the numbers of accidents would remain the same, increase, or decrease and implied a two-tail test of hypothesis.

The second question assumed that there was either no change, or a decrease in the numbers of accidents. It implied that the intersection could not become more dangerous after signalization as this is what most of the motoring public assumes. It required a one-tail test of hypothesis.

Tables 3 and 4 summarize the answers to the first question for both procedures 1 and 2. Care should be exercised in making generalizations concerning those intersections that previous to signalization were four-way stops as there were only six. However, the trends of the changes in the accident patterns of these six intersections usually followed the trends of the changes in the accident patterns of those thirty-two intersections that were previously two-way stops. This is some indication that the data from the intersections with four-way stops are reliable. All conclusions, however, are based upon the intersections that had two-way stops before signalization.

From a review of these tables it is immediately obvious that a very large proportion of the intersections usually did not have a difference in the number of accidents from before to after that was great enough to be considered

Table 3. Percentage of the Thirty-two Two-way Stop Controlled Intersections having a Significant Change in the Indicated Accident Pattern after Signalization.

	Procedure 1		Procedure 2	
	<u>A</u> ¹	<u>B</u>	<u>C</u>	<u>D</u>
<u>Total Accidents</u>				
Significant increase	19	34	16	28
No significant change	81	44	84	50
Significant decrease	0	22	0	22
<u>Right-angle Accidents</u>				
Significant increase	3	16	0	16
No significant change	88	40	91	37
Significant decrease	9	44	9	47
<u>Rear-end Accidents</u>				
Significant increase	37	66	28	56
No significant change	63	34	72	44
Significant decrease	0	0	0	0
<u>Miscellaneous Accidents</u>				
Significant increase	19	25	9	25
No significant change	81	69	91	69
Significant decrease	0	6	0	6

¹ Levels of observation, see page 24.

Table 4. Percentage of the Six Four-way Stop Controlled Intersections having a Significant Change in the Indicated Accident Pattern after Signalization.

	Procedure 1		Procedure 2	
	<u>A</u>	<u>B</u>	<u>C</u>	<u>D</u>
<u>Total Accidents</u>				
Significant increase	17	17	17	17
No significant change	50	50	50	50
Significant decrease	33	33	33	33
<u>Right-angle Accidents</u>				
Significant increase	0	0	0	0
No significant change	50	17	50	17
Significant decrease	50	83	50	83
<u>Rear-end Accidents</u>				
Significant increase	17	50	17	50
No significant change	83	50	83	50
Significant decrease	0	0	0	0
<u>Miscellaneous Accidents</u>				
Significant increase	17	33	0	33
No significant change	83	67	100	67
Significant decrease	0	0	0	0

¹ Levels of observation, see page 24.

statistically significant. This finding is important, but equally important is the fact that for those few intersections which had a change in the number of accidents large enough to be considered significant, the trend was either an increase as for rear-end accidents or a decrease as for right-angle accidents.

The total number of accidents (see Table 2) increased at slightly more than half of the intersections while decreasing at slightly less than half. This increase or decrease was considerable at less than half of the intersections. When the change was considerable, it was more often an increase than a decrease. The effect on the types of accidents, moreover, was important. The number of right-angle accidents usually decreased while rear-end and miscellaneous accidents increased. These numerical changes were as follows:

1. Right-angle accidents decreased at two-thirds of the intersections while increasing at only one-third.
2. Rear-end accidents increased at three-fourths of the intersections, and decreased at only one intersection.
3. Miscellaneous accidents increased at half of the intersections while decreasing at only one-fourth.

Most of the increase in rear-end accidents was usually on the major street (see collision diagrams in Appendix F). The periodic changing of the assigned right-of-way from major to minor street, or vice-versa, is conducive to the rear-end

accident. This condition is compounded by a dilemma zone, an area where the driver has to decide whether to go or to stop when the amber light appears.

Vehicle actuated signal equipment is an attempt by engineers to minimize the number of periodic changes in the assigned right-of-way and to reduce delay. Minor street actuated signals often reduce the number of vehicles required to stop on the major street. Vehicles on both streets, however, are still required to stop at random. This random requirement that vehicles must stop becomes more dangerous if the change from green to red occurs too quickly.

For the twelve intersections in this study with vehicle actuated signals replacing the two-way stops, eleven had significant increases in rear-end accidents. For the twenty intersections which did not have vehicle actuated signals replacing two-way stops, only eight intersections had a significant increase in rear-end accidents. This effect probably resulted from the fact that the vehicle actuated equipment was installed at those intersections where traffic volumes on the major street were much higher than those on the minor street.

No further investigations were made concerning vehicle actuated signal equipment; however, it is suggested that further research be performed on the effects that the installation of vehicle actuated signals may have on intersection accidents.

When the comparisons of accidents were made to answer question 2, the results shown in Table 5 were obtained. It is clear that there usually was not a significant decrease in accidents. A reduction at more than one half of the intersections is only shown for right-angle accidents.

Table 5. Percentage of Intersections having a Significant Decrease in Accidents after Signalization.

<u>Accident Type</u>	Control Before:	Procedure 1				Procedure 2			
		Two-way ¹		Four-way ²		Two-way		Four-way	
		<u>A</u> ³	<u>B</u>	<u>A</u>	<u>B</u>	<u>C</u>	<u>D</u>	<u>C</u>	<u>D</u>
Total Accidents		0	31	33	50	13	34	33	50
Right-angle Accidents		3	50	50	83	22	75	50	83
Rear-end Accidents		0	0	0	0	0	3	0	0
Miscellaneous Accidents		0	6	0	17	6	31	0	33

¹ Thirty-two intersections

² Six intersections

³ Levels of observation, see page 24.

Comparison of Accident Severity

The severity of the accident problem at an intersection is a combination of many factors. Some of these are the number of accidents occurring, the number of injury and fatal accidents occurring, the number of injuries or fatalities and the acuteness of the injuries, and the property damage cost of the accidents.

Because of the few fatalities occurring at the sample intersections, fatalities and fatal accidents were considered as injuries and injury accidents for all comparisons in this study.

If the investigating officer indicated on the accident report form (see Figure 4) that a person was injured, this was considered to be an injury accident. An injury, therefore, included everything from a reported complaint of injury or a scratch to a fatality.

Because of what is being considered to be an injury and because the number of persons injured in an accident is also a function of the number of persons in the vehicles at the time of the accident, no comparisons were made on the numbers of persons injured at the intersections from before to after signalization.

It has just been shown that the total number of accidents did not change significantly after signalization at most intersections.

By dividing the accidents at each intersection into injury and non-injury for the total accidents, as well as

right-angle, rear-end, and miscellaneous accidents, the occurrence of these types of accidents which were injury was compared by using the same techniques previously employed, see Tables 6 and 7.

Most of the intersections did not have a significant change in the number of total accidents which were injury. This finding was also true for right-angle, rear-end, and miscellaneous accidents. However, for those few intersections having a significant change, the change was usually an increase for total, rear-end, and miscellaneous accident types.

Even though the number of total accidents and also the number of total injury accidents did not change significantly at most of the intersections after signalization, this does not necessarily mean that the percent of accidents that were injury did not change. Comparisons of the before and after percentages of accidents that were injury accidents were, therefore, made under both procedures 1 and 2. After an accident had occurred, whether or not it was an injury accident was assumed to be binomially distributed.

When the comparisons were made using procedure 1, no usable results were obtained. This was because the parameter being compared, the percent of the accidents that were injury was sometimes zero. Also the sample sizes of accidents were often very small.

Table 6. Percentage of the Thirty-two Two-way Stop Controlled Intersections having a Significant Change in the Numbers of Injury Accidents after Signalization.

	Procedure 1		Procedure 2	
	<u>A</u>	<u>B</u>	<u>C</u>	<u>D</u>
<u>Total Accidents</u>				
Significant increase	22	38	12	31
No significant change	75	50	85	57
Significant decrease	3	12	3	12
<u>Right-angle Accidents</u>				
Significant increase	6	16	0	16
No significant change	91	68	94	62
Significant decrease	3	16	6	22
<u>Rear-end Accidents</u>				
Significant increase	16	28	0	25
No significant change	84	72	100	75
Significant decrease	0	0	0	0
<u>Miscellaneous Accidents</u>				
Significant increase	9	16	6	22
No significant change	91	84	91	72
Significant decrease	0	0	3	6

¹ Levels of observation, see page 24.

Table 7. Percentage of the Six Four-way Stop Controlled Intersections having a Significant Change in the Numbers of Injury Accidents after Signalization.

	Procedure 1		Procedure 2	
	<u>A</u> ¹	<u>B</u>	<u>C</u>	<u>D</u>
<u>Total Accidents</u>				
Significant increase	17	33	17	33
No significant change	83	67	83	67
Significant decrease	0	0	0	0
<u>Right-angle Accidents</u>				
Significant increase	0	0	0	0
No significant change	100	83	100	83
Significant decrease	0	17	0	17
<u>Rear-end Accidents</u>				
Significant increase	17	33	17	33
No significant change	83	67	83	67
Significant decrease	0	0	0	0
<u>Miscellaneous Accidents</u>				
Significant increase	0	17	0	0
No significant change	100	83	100	100
Significant decrease	0	0	0	0

¹ Levels of observation, see page 24.

The test of hypothesis was then made using procedure 2 at level of observation c (see page 24). The Fisher exact test was used for this test of the two binomial parameters (2). At this level of observation there was a significant change in the percentages for only three intersections and only for total accidents. For right-angle, rear-end, and miscellaneous accidents, there were no significant changes in the percentages of the accidents that were injury for any intersection.

A different level of observation might have yielded results which would have shown trends, but because the mathematical calculations were extremely tedious and tables to simplify calculations were not available for higher observation levels, the hypothesis was not tested at a higher observation level.

An estimate of the change in the percentages of the accidents that were injury was also made by comparing the occurrence of both the injury and non-injury total, right-angle, rear-end, and miscellaneous accidents at each intersection. The changes in the occurrence of the injury and non-injury accidents at the intersections are summarized in Tables 8, 9, 10, and 11.

At the intersections for which signals replaced two-way stops, most intersections did not have significant changes in the numbers of injury and non-injury accidents. For those few intersections with significant changes in injury and non-injury accidents, the change was a trend either an increase or a decrease depending on the accident type.

Table 8. Percentage of the Thirty-two Two-way Stop Controlled Intersections having a Significant Change in the Numbers of Injury and Non-injury Accidents after Signalization (Procedure 1)

	Injury ¹		Non-injury	
	A	B	A	B
<u>Total Accidents</u>				
Significant increase	22	38	19	28
No significant change	75	50	81	56
Significant decrease	3	12	0	16
<u>Right-angle Accidents</u>				
Significant increase	6	16	0	0
No significant change	91	68	88	72
Significant decrease	3	16	12	28
<u>Rear-end Accidents</u>				
Significant increase	16	28	25	53
No significant change	84	72	75	47
Significant decrease	0	0	0	0
<u>Miscellaneous Accidents</u>				
Significant increase	9	16	12	28
No significant change	91	84	88	66
Significant decrease	0	0	0	6

¹ Levels of observation, see page 24.

Table 9. Percentage of the Thirty-two two-way Stop Controlled Intersections having a Significant Change in the Numbers of Injury and Non-injury Accidents after Signalization (Procedure 2).

	Injury		Non-injury	
	<u>C</u> ¹	<u>D</u>	<u>C</u>	<u>D</u>
<u>Total Accidents</u>				
Significant increase	12	31	12	31
No significant change	85	57	88	50
Significant decrease	3	12	0	19
<u>Right-angle Accidents</u>				
Significant increase	0	16	0	3
No significant change	94	62	88	69
Significant decrease	6	22	12	28
<u>Rear-end Accidents</u>				
Significant increase	0	25	22	38
No significant change	100	75	73	59
Significant decrease	0	0	0	3
<u>Miscellaneous Accidents</u>				
Significant increase	0	16	6	22
No significant change	100	81	91	72
Significant decrease	0	3	3	6

¹ Levels of observation, see page 24.

Table 10. Percentage of the Six Four-way Stop Controlled Intersections having a Significant Change in the Numbers of Injury and Non-injury Accidents after Signalization (Procedure 1).

	Injury		Non-injury	
	<u>A</u> ¹	<u>B</u>	<u>A</u>	<u>B</u>
<u>Total Accidents</u>				
Significant increase	17	33	0	17
No significant change	83	67	67	50
Significant decrease	0	0	33	33
<u>Right-angle Accidents</u>				
Significant increase	0	0	0	0
No significant change	100	83	50	33
Significant decrease	0	17	50	67
<u>Rear-end Accidents</u>				
Significant increase	17	33	17	50
No significant change	83	67	83	50
Significant decrease	0	0	0	0
<u>Miscellaneous Accidents</u>				
Significant increase	0	17	0	17
No significant change	100	83	100	83
Significant decrease	0	0	0	0

¹ Levels of observation, see page 24.

Table 11. Percentage of the Six Four-way Stop Controlled Intersections having a Significant Change in the Numbers of Injury and Non-injury Accidents after Signalization (Procedure 2).

	¹ Injury		Non-injury	
	<u>C</u>	<u>D</u>	<u>C</u>	<u>D</u>
<u>Total Accidents</u>				
Significant increase	17	33	0	17
No significant change	83	67	67	50
Significant decrease	0	0	33	33
<u>Right-angle Accidents</u>				
Significant increase	0	0	0	0
No significant change	100	83	50	17
Significant decrease	0	17	50	83
<u>Rear-end Accidents</u>				
Significant increase	17	33	0	33
No significant change	83	67	0	67
Significant decrease	0	0	0	0
<u>Miscellaneous Accidents</u>				
Significant increase	0	0	0	17
No significant change	100	100	100	83
Significant decrease	0	0	0	0

¹ Levels of observation, see page 24.

For total accidents there was a slightly greater percentage of intersections having a significant decrease in the occurrence of non-injury accidents than a significant decrease in injury accidents and a greater percentage of intersections having a significant increase in injury accidents than a significant increase in non-injury accidents. For right-angle accidents there was a tendency to have a larger percentage of accidents that were injury as more intersections had a significant decrease in non-injury right-angle accidents than a significant increase and as more intersections had a significant increase in right-angle injury accidents that a significant decrease. For rear-end accidents there was no indication that the percent which were injury tended to increase or decrease.

Total property damage accident costs increased at 56 percent of the intersections with two-way stops prior to signalization (see Table 12). The percentages of intersections having an increase in accident property damage costs were similar to the percentages of intersections having an increase in accidents (see Table 2). The linear correlation coefficients between total accidents and total property damage costs were 0.83 and 0.86 for before and after signalization, respectively. Since total accidents and total property damage costs were correlated, if accidents did not change significantly at an intersection, no change in the total property damage costs should also be expected.

Table 12. Percentage of Intersections Having an Increase in the Total Property Damage Costs .

<u>Accident Pattern</u>	<u>Percent of Intersections</u>
<u>Two-way Stops Prior to Signalization¹</u>	
Total Accidents	56
Right-angle accidents	34
Rear-end accidents	72
Miscellaneous accidents	66
<u>Four-way Stops Prior to Signalization²</u>	
Total Accidents	50
Right-angle accidents	33
Rear-end accidents	83
Miscellaneous accidents	33

¹ Thirty-two intersections .

² Six intersections .

Because most intersections did not have significant changes in total accidents, accidents which were injury, percentages of accidents which were injury, and total property damage costs, most intersections did not have a significant change in the severity of the total accident pattern.

Because one or two spectacular accidents at an intersection may distort the accident severity picture, the accident data for the before periods of all intersections were combined. Likewise, the data of the after periods were combined. The combined data were then compared. Validity of results from comparisons of the data grouped in this manner depended upon the following additional assumptions. The probability of an accident with given characteristics was assumed to be the same at all the studied intersections for both the before and after periods. The sampled intersections were considered to be representative of all intersections which had recently been signalized.

The ratios of all fatal accidents to all injury accidents to all property damage accidents are often used as a measure of accident severity. The ratios were 1:21:63 for the intersections with the two-way stops and 1:30:81 for the same intersections after signalization. The ratios were 0:10:49 for the intersections with four-way stops and 1:19:35 for the same intersections after signalization. Combining the data for all the intersections after signalization the ratios are 1:28:75.

The number of accidents occurring is part of the measure of the severity of accidents at intersections. Table 13 presents the summation of the accidents occurring at all the intersections. The values of Table 13 indicate that the total number of accidents increased after the intersections were signalized. This increase in total accidents was caused by increases in rear-end and miscellaneous accidents overshadowing the decrease in right-angle accidents.

By a knowledge of the number of accidents that had an injury or fatality (Table 14), it was possible to calculate the percentage of accidents which were injury (see Table 15).

The increase in the percentages of right-angle accidents which were injury was probably due to an increase in the number of drivers that did not obey the control device. With two-way stops only the minor street traffic could run the control device. With signals, part of the major street traffic along with part of the minor street traffic, the sum being greater than the minor street traffic volume, had the opportunity not to obey the control device. The increase in the severity of rear-end accidents, as well as the large increase in their numbers, was due to the many additional stops required of the high speed traffic on the major street after signalization.

Property damage costs are considered another part of intersection accident severity.

Table 13. Numbers of Accidents.

<u>Accident Pattern</u>	<u>Adjusted Before</u>	<u>After</u>
<u>Two-way Stops Prior to Signalization</u> ¹		
Total Accidents	388	451
Right-angle accidents	201	105
Rear-end accidents	53	170
Miscellaneous accidents	134	176
<u>Four-way Stops Prior to Signalization</u> ²		
Total Accidents	67	55
Right-angle accidents	49	13
Rear-end accidents	5	32
Miscellaneous accidents	14	19

¹ Thirty-two intersections.

² Six intersections.

Table 14. Numbers of Fatal and Injury Accidents.

<u>Accident Pattern</u>	<u>Adjusted Before</u>	<u>After</u>
<u>Two-way Stops Prior to Signalization¹</u>		
Total Accidents	100	126
Right-angle accidents	69	46
Rear-end accidents	7	42
Miscellaneous accidents	24	37
<u>Four-way Stops Prior to Signalization²</u>		
Total accidents	11	20
Right-angle accidents	9	6
Rear-end accidents	0	9
Miscellaneous accidents	2	5

¹ Thirty-two intersections.

² Six intersections.

Table 15. Percentage of Accidents that were Fatal or Injury Accidents.

<u>Accident Pattern</u>	<u>Before</u>	<u>After</u>
<u>Two-way Stops Prior to Signalization¹</u>		
Total Accidents	23	28
Right-angle accidents	34	44
Rear-end accidents	13	25
Miscellaneous accidents	18	22
<u>Four-way Stops Prior to Signalization²</u>		
Total Accidents	17	36
Right-angle accidents	19	46
Rear-end accidents	0	28
Miscellaneous accidents	17	26

¹ Thirty-two intersections.

² Six intersections.

The total property damage cost of total accidents increased after signalization. Total right-angle property damage cost decreased while rear-end and miscellaneous property damage costs increased after signalization.

The standard deviation of the costs for both the before and the after accidents was larger than the average costs, indicating large variation. Histograms showing the percent of accidents having a property damage cost within various dollar ranges were drafted to show this variation in the property damage costs and to show the before to after change in such costs (see Figures 7, 8, 9, 10, 11, 12, 13 and 14). Costs shown did not reflect possible changes in cost due to inflation; however, the difference in time between the before and after periods was slightly less than two years.

Above a property damage cost of 400 dollars there was little change in any pattern of costs after signalization for any accident type.

Below 400 dollars there was a clearer indication of a change in the property damage costs after signalization. There was more of the lower cost accidents, 0 to 200 dollars. This was due to the increase in rear-end accidents of which many were low cost. Right-angle accidents decreased in number, but a greater percentage cost between 200 and 400 dollars.

For the intersections that had four-way stops before signalization and for some accident patterns, there was much

variation in the property damage cost histograms from before to after. However, this is suspected to be largely due to the small number of accidents that were studied.

With the accident data grouped for all the before periods and for all the after periods, the severity of the intersection accident picture increased after signalization.

FIGURE 7. VARIATION IN PROPERTY DAMAGE COST OF
TOTAL ACCIDENTS

NOTE: 32 INTERSECTIONS
USED

FIGURE 8. VARIATION IN PROPERTY DAMAGE COST OF
RIGHT ANGLE ACCIDENTS

FIGURE 9. VARIATION IN THE PROPERTY DAMAGE COST
OF REAR-END ACCIDENTS

FIGURE 10. VARIATION IN THE PROPERTY DAMAGE COST OF MISCELLANEOUS ACCIDENTS

FIGURE II. VARIATION IN THE PROPERTY DAMAGE COST
OF TOTAL ACCIDENTS

FIGURE 12. VARIATION IN THE PROPERTY DAMAGE COST
OF RIGHT ANGLE ACCIDENTS

FIGURE 13. VARIATION IN THE PROPERTY DAMAGE COST
OF REAR END ACCIDENTS

FIGURE 14. VARIATION IN THE PROPERTY DAMAGE COST
OF MISCELLANEOUS ACCIDENTS

Comparison of Accidents During Daylight

The number of hours of daylight is constant from year to year, and it was assumed that the portion of driving during daylight hours did not change during the study period of each intersection. After an accident had occurred, whether it occurred during daylight hours was considered to be binomially distributed, and tests of hypothesis were performed using procedures 1 and 2 on an intersection basis. It was hoped that this analysis would indicate if the percentage of accidents that occurred during daylight hours significantly changed after the two-way stop controlled intersections were signalized. However, no usable results were obtained from these tests.

As with injury and non-injury accidents, the occurrences of an accident during daylight or dark hours was also considered to be Poisson distributed. The changes in the occurrence of daylight and dark accidents were calculated and are presented in Tables 16 and 17. In general, for most intersection there was little significant change in the number of accidents occurring during daylight or dark hours from before to after signalization of two-way stop controlled intersections.

Even when all the before accidents and all the after accidents are grouped and analyzed under assumptions similar to those made for the grouped accident severity comparisons, the percentage of total accidents occurring during daylight hours did not change appreciably for those intersections having two-way stops prior to signalization (see Table 18).

Table 16. Percentage of the Thirty-two Two-way Stop Controlled Intersections having a Significant Change in the Numbers of Accidents During Daylight and Dark Hours after Signalization (Procedure 1).

	Daylight ¹		Dark	
	A	B	A	B
<u>Total Accidents</u>				
Significant increase	12	34	16	38
No significant change	85	44	84	56
Significant decrease	3	22	0	6
<u>Right-angle Accidents</u>				
Significant increase	3	22	0	3
No significant change	88	50	100	88
Significant decrease	9	28	0	9
<u>Rear-end Accidents</u>				
Significant increase	25	56	9	47
No significant change	75	44	91	53
Significant decrease	0	0	0	0
<u>Miscellaneous Accidents</u>				
Significant increase	9	31	3	25
No significant change	91	69	97	69
Significant decrease	0	0	0	6

¹ Levels of observation, see page 24.

Table 17. Percentage of the Thirty-two Two-way Stop Controlled Intersections having a Significant Change in the Numbers of Accidents During Daylight and Dark Hours After Signalization (Procedure 2).

	Daylight		Dark	
	<u>C</u> ¹	<u>D</u>	<u>C</u>	<u>D</u>
<u>Total Accidents</u>				
Significant increase	12	25	6	28
No significant change	85	53	94	66
Significant decrease	3	22	0	9
<u>Right-angle Accidents</u>				
Significant increase	0	16	0	3
No significant change	91	50	100	78
Significant decrease	9	34	0	19
<u>Rear-end Accidents</u>				
Significant increase	12	41	0	38
No significant change	88	59	100	62
Significant decrease	0	0	0	0
<u>Miscellaneous Accidents</u>				
Significant increase	3	25	3	22
No significant change	97	69	97	69
Significant decrease	0	6	0	9

¹ Levels of observation, see page 24.

Table 18. Percentages of Accidents During Daylight Hours.

<u>Accident Patterns</u>	<u>Before</u>	<u>After</u>
<u>Two-way Stops Prior to Signalization</u> ¹		
Total Accidents	77	75
Right-angle accidents	79	83
Rear-end accidents	81	72
Miscellaneous accidents	72	73
<u>Four-way Stops Prior to Signalization</u> ²		
Total Accidents	81	69
Right-angle accidents	84	62
Rear-end accidents	75	87
Miscellaneous accidents	78	53

¹ Thirty-two intersections.

² Six intersections.

The considerable change in the percentages of the accidents that occurred during daylight hours for those intersections that had had four-way stops previous to signalization might have resulted from the small numbers of accidents in the sample (see Table 13). Further study of the change in the daylight and night accidents at intersections where the control device is changed from four-way stops to signals appears desirable.

Comparison of Accidents on Dry Pavement

It was assumed that the number of rainy and snowy days before and after was the same and that they occurred randomly for each intersection. Because the wet days occurred randomly, the intersections could be grouped with a minimum of assumptions and the totals for the before and after periods compared.

The percents of accidents occurring on wet or dry pavement are presented in Table 19 and an indication is made as to which changes are significant.

There were significantly less accidents on dry pavements after signalization. This decrease was due to increases in rear-end collisions and increases in right-angle collisions on wet pavements.

Because more vehicles are required to stop, and because more stops are made under "surprise" conditions at intersections which are signalized than when they were two-way stop controlled, and because quick stopping is more difficult on

Table 19. Percentages of Accidents on Dry Pavement.

Accident Pattern	Percentages		Significant Change			
	Before	After	Procedure			
	1		2			
	A		B			
	1		C			
	D		D			
Two-way Stops Prior to Signalization ²						
Total Accidents	63	58	None	Decrease	None	Decrease
Right-angle accidents	66	58	None	Decrease	None	Decrease
Rear-end accidents	59	49	None	Decrease	None	Decrease
Miscellaneous accidents	60	67	None	Increase	None	Increase
Four-way Stops Prior to Signalization ³						
Total Accidents	53	69	Increase	Increase	None	Increase
Right-angle accidents	56	77	None	Increase	None	Increase
Rear-end accidents	25	61	Increase	Increase	Increase	Increase
Miscellaneous accidents	50	74	None	Increase	None	Increase

1

2 Thirty-two intersections.

3 Six intersections.

wet pavement, it is not surprising that the number of right-angle and rear-end accidents on wet pavement increased after signalization. Both of these types of accidents increase because of the difficulty of stopping on wet pavement, a condition which many drivers do not adequately consider.

The decrease in accidents on wet pavement at intersections that had had four-way stops prior to signalization might be accounted for by the decrease in the number of vehicles that are required to stop on the slippery surface.

Changes in Accidents During Each Hour of Day, Day of Week,
and Month of Year

The next three groupings of accidents for the before and after periods -- hour of day, day of week, and month of year -- are presented in two ways: the percent of accidents (Figures 15, 17, and 19) and by relative accident rates (Figures 16, 18, and 20). The latter considers traffic volume fluctuations (21) occurring each hour, day, or month.

The percents of accidents per time period are of interest to enforcement officials when determining manpower needs. Relative accident rates are a measure of hazard. The rates are relative indexes of the accident hazard for each of the time periods charted (hour, week, and month).

In general there was little change for any of the groups from before to after. The afternoon hours had more accidents both before and after, but this is to be expected, as more driving is done during these hours. The accident rates, however, indicated that the early morning hours were the most hazardous.

(SOURCE: K. B. WOODS, HIGHWAY ENGINEERING HANDBOOK)

FIGURE 15. HOURLY VARIATIONS OF TRAFFIC ACCIDENTS AND VOLUME

FIGURE 16. HOURLY VARIATIONS OF THE RELATIVE ACCIDENT RATE

(SOURCE K B WOODS, HIGHWAY ENGINEERING HANDBOOK)

FIGURE 17. DAILY VARIATIONS OF TRAFFIC ACCIDENTS AND VOLUME

FIGURE 18. DAILY VARIATIONS OF THE RELATIVE ACCIDENT RATE

(SOURCE: K.B. WOODS, HIGHWAY ENGINEERING HANDBOOK)

FIGURE 19. MONTHLY VARIATIONS OF TRAFFIC ACCIDENTS AND VOLUME

FIGURE 20. MONTHLY VARIATIONS OF THE RELATIVE ACCIDENT RATE

With the exception of Wednesday, which was slightly more hazardous after signalization, there was little variation in the daily accident hazard.

December was a hazardous driving month, regardless of the control device. This is the usual beginning of bad winter weather and the month in which most Christmas shopping is done. After signalization, April, May, and June, which are the beginning of spring and warm weather, were less hazardous, while February was more hazardous.

Changes in Accident Rates Correlated with Speed

The average of the sum of the posted speed limits for major and minor roads was graphed with respect to the average accident rate (accidents per million entering vehicles) for groups of intersections. The intersections were grouped according to the sum of the speeds: intersections for which the sum of posted speeds was less than 60 mph, equal to 60 mph, and greater than 60 mph (see Figure 21).

There was a slight increase in average accident rates as the average sum of the posted speed limits increased from 45 to 80 mph. There was no significant difference in this trend for accidents occurring at the two-way stop intersections or for the same intersections when signalized.

There was much variation in accident rates within each group. No check was made at any of the intersections to ascertain if the posted speed limit represented the average or 85 percentile speed or any other speed percentile.

FIGURE 21. AVERAGE SUM OF THE SPEED LIMITS OF THE INTERSECTING ROADS VERSUS THE AVERAGE ACCIDENT RATE FOR THE INTERSECTIONS

Changes in Accidents Correlated with Pretimed Signal Warrants

Since the warrants for pretimed traffic signals (see Appendix A) are widely used by traffic officials when investigating the request for a traffic signal, it was decided to group the intersections of this study with respect to meeting (Group 1) or not meeting (Group 2) these warrants. A third group (Group 3) of intersections, composed of some intersections from the other two groups, was also formed. These latter intersections had five or more accidents of the type often considered correctable by a signal, right-angle accidents, within the preceding twelve months.

Each intersection within the groups was then plotted on a graph of the major street volume and the larger minor street entering volume (see Figures 22, 23, and 24). Rural and suburban intersections are plotted together on the charts. The volume warrant used to determine if a signal was warranted was determined by the estimated 85 percentile speed on the approaches to the intersection. An indication was also noted with each plot of the extent of the change in the total accident pattern after signalization (significant increase, absolute increase, no change, absolute decrease, or significant decrease) using procedure 2 at level of observation D.

Those intersections that met the warrants (Group 1) had a tendency to have:

FIGURE 22. CHANGES IN ACCIDENTS CORRELATED WITH TRAFFIC VOLUME AND PRETIMED SIGNAL WARRANTS (GROUP 1 - INTERSECTIONS WHICH MEET THE WARRANTS)

FIGURE 23. CHANGES IN ACCIDENTS CORRELATED WITH TRAFFIC VOLUME AND PRETIMED SIGNAL WARRANTS (GROUP 2- INTERSECTIONS WHICH DID NOT MEET WARRANTS)

FIGURE 24. CHANGES IN ACCIDENTS CORRELATED WITH TRAFFIC VOLUME AND PRETIMED SIGNAL WARRANTS (GROUP 3- INTERSECTIONS WHICH HAD FIVE OR MORE RIGHT- ANGLE ACCIDENTS IN THE PRECEDING TWELVE MONTHS)

1. A significant increase in total accidents if the ratio of the major street entering volume to the larger minor street entering volume was greater than four to one.
2. No significant change in total accidents if the ratio of major street entering volume to the large minor street entering volume was less than four to one.

A decrease in accidents, however, did occur at five of the twelve intersections in this group. Two of these intersections had a significant decrease and were in the portion of the chart where other intersections had increases in accidents. Most of the intersections which had a decrease in accidents after signalization had a significant decrease in right-angle accidents. For most of these intersections the number of right-angle accidents for the two year before period was greater than ten and as high as 25. Almost every intersection which had an increase in accidents in the after period had less than ten right-angle accidents in the two year before period.

Even though each of the twelve intersections in Group 1 met the volume warrants for the installation of a signal, seven had an increase in accidents. This increase was significant at four. It would appear that one can expect accidents to increase after signalization under current warrants if the ratio of major street volume to larger minor street entering volume is greater than four to one unless there are at least five or more correctable, right-angle, accidents per year.

Those intersections which did not meet the warrants (Group 2) had the following volume characteristics: Almost all of the intersections having more than 8000 vehicles per day on the major street had less than 2000 entering vehicles per day on the larger minor street approach. This situation occurred because almost every signalized intersection with volumes greater than these was signalized prior to the study periods used in this research.

The intersections in Group 2 tended to have:

1. An increase in total accidents if the ratio of the volume on the major street to that on the larger minor street was greater than six to one.
2. Little change or a decrease in accidents if the ratio of the volume on the major street to that on the larger minor street is less than six to one.

Some exceptions to the above rules are evident, however. Again the factor of a large number of right-angle accidents prior to signalization appears to be important for those intersections which had a decrease in accidents and which had an ADT of over 8000 vehicles on the major street. For low volume intersections in this group (less than 8000 vehicles per day on the major street), an increase in accidents after signalization occurred at only four out of thirteen intersections; at two of these four it was significant. Most of these intersections had less than ten accidents prior to signalization and apparently because of the low volumes, did

not have an increase often. It would appear that the installation of traffic signals at intersections where the traffic volume is low (below 3000 vehicles per day) on the major street and of significant volume on the larger minor street will not usually result in an increase in accidents.

Those intersections in Group 3 that had five or more accidents of the type correctable by a signal (right-angle) tended to have a decrease in total accidents. This decrease was significant for those intersections with a major street ADT of less than 8000 vehicles. The decrease was usually due to a significant decrease in right-angle accidents. For the higher volume intersections (major street ADT greater than 8000 vehicles) there often was, however, a significant increase in rear-end accidents, thus overshadowing the significant decrease in right-angle accidents.

Accidents Per Year Correlated with Traffic Volumes

Previous studies of intersection accidents correlated traffic volume to accidents, and because of this, some adjustment was made to the before signalization numbers of accidents to account for the growth in traffic volume from the before period to the after period. Various models were investigated to determine a relationship between traffic volume and accidents from the data of this research. No relationship could be determined because of the lack of range of the intersection traffic volumes, as they were at or below those minimum values set forth in the warrants for pretimed signals (see Appendix A).

Charts relating major and minor street total entering volumes and accident rates (accidents per year) are presented in Figure 25. Other characteristics of the intersections were also studied and the following trends were observed for both the before (with two-way stops) and the after (with signalization) periods:

1. Low accident rates occurred at intersections where the major street had a volume of less than 5000.
2. Intersections in residential areas of large cities and commercial areas of very small towns had lower rates than intersections in fringe areas of large cities or rural areas near large cities.
3. Accident rates tended to increase with city size.

Comparison to Solomon's Procedure

In the section of Previous Investigations of this report a review of a study by David Solomon was made (16). Solomon compared the total number of accidents occurring before and after signalization of thirty-nine intersections with three, four, or more approaches. Solomon grouped the before numbers and after numbers of accidents at all intersections for making the comparisons and for drawing conclusions. He did not adjust for traffic growth which he stated was about 11 percent. To account for this traffic growth, an adjustment was made to the number of before signalization accidents by the ratio of after volume to before volume. These adjusted

FIGURE 25. ACCIDENT RATES CORRELATED TO MAJOR AND MINOR STREET TRAFFIC VOLUMES

values are shown in Table 20. Table 21 presents a comparable summary of the accident data of this study.

With respect to changes in accident occurrence, the group data of this study followed closely the trends which Solomon observed from his data. Total accidents increased slightly, the increase in rear-end accidents being larger than the decrease in right-angle accidents.

The difference in the magnitude and direction of the percentage change in the number of fatalities is not important because of the small number of fatalities and no conclusion should be made.

A better description than that presented in Table 20 of the change in the number of injuries was a written passage by Solomon that injuries tended to remain constant at three-leg intersections, to increase slightly at four-leg undivided intersections, to decrease slightly at four-leg divided intersections, and to decrease at intersections with more than four approaches. All intersections of this study had four approaches and all but three were four-leg undivided. The slight increase in the number of injuries in this study was the same as Solomon found.

Both before and after signalization the accidents reviewed by Solomon experienced more injuries per accident than the accidents of this study. This was probably due to factors other than signalization. The percent change in the number of injuries was similar, however.

Table 20. Summary of Solomon's Data Adjusted for the Traffic Growth.

	<u>Adjusted Before</u>	<u>After</u>	<u>Percent Change</u>
Total number of accidents	514	569	+ 11
Right-angle accidents	288	128	- 56
Rear-end accidents	106	288	+171
Miscellaneous accidents	119	153	+ 29
Number of fatalities	16	7	- 56
Number of injuries	420	304	- 28
Percentage of accidents in daylight		<u>Before</u>	<u>After</u>
		59	63
Percentage of accidents on dry pavement		84	76

Table 21. Summary of Study Data for Comparison to Solomon's Data.

	<u>Adjusted Before</u>	<u>After</u>	<u>Percent Change</u>
Total number of accidents	454	506	+ 11
Right-angle accidents	243	118	- 53
Rear-end accidents	57	193	+239
Miscellaneous accidents	143	195	+ 24
Number of fatalities	5	6	+ 20
Number of injuries	198	224	+ 13
Percentage of accidents in daylight	<u>Before</u>	<u>After</u>	
	78	74	
Percentage of accidents on dry pavement	65	59	

There is a difference in the direction of the change of the percent of accidents occurring during daylight hours between the studies. The change in both studies, an increase in Solomon's and a decrease in this study, however, is slight.

In both studies there were more accidents on wet pavements.

This study utilized analytical techniques which considered accident data on an intersectional basis so as to minimize the affects of differences between intersections. Solomon used a technique which grouped the data of all intersections. The similar results obtained from each study indicate that either technique may be acceptable for the type of study made in this research.

Comparison to Syrek's Procedure

As noted in the Previous Investigation section of this study, one earlier study, that by Daniel Syrek, developed a model for predicting intersection accidents rates and the change in accident rates to be expected when the control device was changed. In Syrek's model, a range of major and minor street traffic volumes and an intersection control device defined a given accident rate.

Each of Syrek's volume groupings represented 20 to 50 intersections. The total number of intersections used in this study precluded development of a model similar to Syrek's; however, the intersections of this study were grouped according to Syrek's volume groupings (see Figure 26). The average

FIGURE 26. PLACEMENT OF INTERSECTIONS WITH RESPECT TO SYREK'S GROUPINGS

accident rates were then computed for each grouping of the intersections for two-way stop and signal controlled intersections (see Table 22).

The average accidents rates computed for each such group in this study are greater than the corresponding rates found by Syrek. The trend in the rates by group and within a group do follow the trends of Syrek's rates. For a given set of major and minor street traffic volumes the total accident rate tends to increase slightly when signals replace two-way stops. This is due to a large increase in the rear-end accident rate overshadowing the decrease in the right-angle accident rate. Both the fatal and injury accident rate and the property damage only accident rate increase correspondingly with the total accident rate when the change in control device is made. This similarity between the trends in accident rates as determined in this study and Syrek's rates using major and minor street volume groupings indicates that either approach is valid.

Comparison to Webb's Procedure

A comparison was also made to another study, that of George Webb (20), discussed in Previous Investigations. Webb developed mathematical models based upon a function of major and minor street volumes to predict the number of accidents per year at signalized intersections. Using Webb's graph of his Semi-Urban model, the suburban intersections of this study

Table 22. Average Accident Rates¹ with Intersections Grouped According to Syrek's Volume Groupings.

Volume Group Accident Type	A		B		TWO-WAY STOPS C		D		O		SIGNALS P				Q	
	Syrek	Study	Syrek	Study	Syrek	Study	Syrek	Study	Syrek	Study	Syrek	Study	Syrek	Study	Syrek	Study
T	.72	2.12	.49	1.13	.26	.86	.14	.57	.66	1.59	.45	1.36	.36	1.44		
RA	.60	1.37	.41	.53	.17	.16	.09	.21	.30	.39	.27	.39	.10	.23		
RE	.07	.26	.06	.15	.05	.13	.02	.14	.19	.55	.10	.49	.21	.69		
LT TN	.05	.16	.02	.08	.04	.13	.03	.07	.17	.24	.08	.14	.05	.15		
O	--	.33	--	.42	--	.44	--	.15	--	.41	--	.34	--	.37		
F&I	.34	.64	.18	.22	.11	.06	.04	.17	.26	.56	.17	.37	.11	.40		
PD	.38	1.28	.31	.94	.15	.81	.10	.49	.40	1.03	.28	.99	.25	1.07		

¹ Accidents per million entering vehicles .

² Total accidents: $T = RA + RE + LT \text{ TN} + O = F\&I + PD$.

RA: Right-angle accidents .

RE: Rear-end accidents .

LT TN: Left-turn accidents .

O: Other accidents (not used in Syrek's work) .

F&I: Fatal and injury accidents .

PD: Property damage accidents .

were plotted on the graph with four symbols to indicate total annual accident frequency (see Figure 27).

The intersections with less than five accidents per year did have major and minor street traffic volumes from which Webb's model would predict these accident frequencies quite well. The other intersections, however, had accident frequencies that were much greater than Webb's model would have predicted from their traffic volumes.

Overall, the accident frequencies and traffic volumes of the intersections of this study did not follow Webb's model very well.

FIGURE 27. PLACEMENT OF INTERSECTIONS ON GRAPH OF WEBB'S SEMI-URBAN MODEL

SUMMARY OF RESULTS

The primary question to be answered by this research was how the pattern and volume of accidents at a two-way stop controlled intersection could be expected to change with the installation of a traffic signal.

The following results concerning such changes were obtained from an analysis of observed changes at thirty-two intersections in Indiana at which traffic signals replaced two-way stops. Unless specifically noted the observed changes in accidents at six additional intersections for which traffic signals replaced four-way stops followed the same trends.

1. A very large proportion of the intersections usually did not have a difference in the number of accidents from before to after that was great enough to be considered statistically significant. For those few intersections which had a change in the number of accidents large enough to be considered important, the trend was an increase for rear-end and miscellaneous accidents and a decrease as for right-angle accidents.
2. The number of right-angle accidents decreased at two-thirds of the intersections while increasing at only one-third.

3. The number of rear-end accidents increased at three-fourths of the intersections, and decreased at only one intersection out of 32.
4. The number of miscellaneous accidents increased at half of the intersections, while decreasing at only one-fourth.
5. With accidents for the before and after signalization periods adjusted to reflect equal traffic volumes during the two periods, the total number of accidents at all thirty-eight intersections after signalization to those before signalization (under stop-sign control) compared as follows:
 - a. Total accidents increased 11 percent.
 - b. Right-angle accidents decreased 53 percent.
 - c. Rear-end accidents increased 248 percent.
 - d. Miscellaneous accidents increased 32 percent.
6. Most of the intersections did not have a significant change in the number of total accidents which were injury. This finding was also true for right-angle, rear-end, and miscellaneous accidents. However, for those few intersections having a significant change, the change was usually an increase for total, rear-end, and miscellaneous accidents.
7. Total property damage costs were highly correlated to the total number of accidents occurring. The linear correlation coefficient values were 0.83 for the stop-sign controlled intersections, before

period, and 0.86 for the signalized intersections, after period.

8. The percentage of total accidents within a given range of property damage costs did not change significantly after signalization. There was an increase in the percentage of right-angle accidents with medium property damage costs and in rear-end accidents with low costs.
9. The percentage of accidents which occurred during daylight hours did not change significantly after signalization.
10. The percentage of accidents occurring on wet pavements increased after signalization. This was true for total accidents as well as for right-angle and rear-end accidents. For those intersections with four-way stops prior to signalization, the accidents on wet pavements decreased after signalization.
11. There was little change in the percentage of accidents which occurred during a given hour of the day, day of the week, or month of the year after signalization.
12. There was a slight increase in the average intersection accident rate as the sum of the major and minor street speed limits of an intersection increased. There was almost no difference in these

average accident rates from before to after signalization.

13. For those intersections which met the warrants of the Manual on Uniform Traffic Control Devices for Streets and Highways (9) for pretimed signals, there was generally an increase in the number of total accidents if the ratio of the major street traffic to the larger minor street traffic was greater than four to one.
14. For those intersections which did not meet the volume warrants for pretimed signals, there was generally little change in total accidents if the ratio of the volume on the major street to that on the larger minor street was less than six to one. There was an increase in total accidents if the ratio was greater than six to one.
15. Those intersections with five or more right-angle accidents per year under stop sign control conditions generally had a decrease in total accidents after signalization. Those with less than five right-angle accidents per year under stop sign control conditions usually had an increase in total accidents after signalization.

CONCLUSIONS

The installation of traffic signals at an intersection under current practices in Indiana did not usually result in fewer accidents occurring at that intersection. In fact, a large proportion of the intersections did not have a change in the number of accidents that was great enough to be considered statistically significant. For those intersections which did have a change in the numbers of the various accident types large enough to be considered significant, the trend was an increase in total, rear-end and miscellaneous accidents and a decrease in right-angle accidents.

The change in the composition of the total number of accidents was very definite. Right-angle accidents normally decreased, while rear-end accidents increased. The remaining or miscellaneous accidents increased more often than decreased. An increase in rear-end accidents often overshadowed the decrease in right-angle accidents and an increase in total accidents often occurred. On the other hand, when there were five or more right-angle accidents per year prior to signalization, the increase in rear-end accidents was not usually large enough to balance the decrease in right-angle accidents and a decrease in total accidents occurred.

The severity of the overall accident condition did not change at most intersections as most intersections had no significant change in the number of total accidents, the number of accidents which were injury and the amount of the property damage cost. When there was a significant change in these accident characteristics, the trend was an increase.

BIBLIOGRAPHY

BIBLIOGRAPHY

1. Baerwald, J. E., Traffic Engineering Handbook, Institute of Traffic Engineers, 1965.
2. Brownlee, K. A., Statistical Theory and Methodology in Science and Engineering, John Wiley & Sons, Inc., New York, 1965.
3. Burr, I. W., Engineering Statistics and Quality Control, McGraw-Hill Book Company, Inc., New York, 1953.
4. Finney, D. J., "The Fisher-Yates Test of Significance in 2×2 Contingency Tables," Biometrika, XXXV (May, 1948), 145-156.
5. Harvard University Press, Tables of the Cumulative Binomial Probability Distribution, Harvard University Press, Cambridge, Mass., 1955.
6. Indiana Traffic Crash Facts, Indiana Office of Traffic Safety, 1963.
7. Indiana Traffic Crash Facts, Indiana Office of Traffic Safety, 1964.
8. Latscha, R., "Tests of Significance in a 2×2 Contingency Table: Extension of Finney's Table," Biometrika, XL (June, 1953), 74-86.
9. Manual on Uniform Traffic Control Devices for Streets and Highways, U.S. Department of Commerce, Bureau of Public Roads, Washington, D.C., 1961.
10. McMonagle, J. Carl, "Relation of Traffic Signals to Intersection Accidents," Bulletin 74, Highway Research Board, 1953.
11. Michaels, Richard M., "Two Simple Techniques for Determining the Significance of Accident-Reducing Measures," Public Roads, Bureau of Public Roads, U. S. Department of Commerce, October, 1959.
12. Molina, E. C., Poisson's Exponential Binomial Limit, D. Van Nostrand Company, Inc., New York, 1942.

13. Ostle, B., Statistics in Research, The Iowa State University Press, Ames, Iowa, 1963.
14. Peterson, A. O., "An Analysis of Traffic Accidents on a High-Volume Highway," Thesis Purdue University, 1965.
15. Schwar, Johannes F. and Puy-Huarte, Jose, Statistical Methods in Traffic Engineering, The Ohio State University, Columbus, Ohio, August, 1964.
16. Solomon, David, "Traffic Signals and Accidents in Michigan," Public Roads, Bureau of Public Roads, October, 1959.
17. Syrek, Daniel, "Accident Rates at Intersections," Traffic Engineering, Institute of Traffic Engineers, May, 1955.
18. Traffic Control and Roadway Elements, The Automotive Safety Foundation, Washington, D.C., 1963.
19. Votaw, David F., and Herbert S. Levinson, Elementary Sampling for Traffic Engineers, The Eno Foundation for Highway Traffic Control, Sangatuck, Conn., 1962.
20. Webb, George M., "The Relation Between Accidents and Traffic Volumes at Signalized Intersections," Institute of Traffic Engineers' Proceedings, 1955.
21. Woods, K. B., Highway Engineering Handbook, McGraw-Hill Book Company, Inc., New York, 1960.
22. Yamane, T., Statistics, An Introductory Analysis, Harper & Row, New York, 1964.

APPENDIX A

WARRANTS FOR PRETIMED SIGNALS

APPENDIX A

WARRANTS FOR PRETIMED SIGNALS

The Manual on Uniform Traffic Control Devices for Streets and Highways (9) includes warrants that an intersection should meet before a pretimed traffic signal is installed. These warrants have become guidelines for the installation of any type of signal control equipment. The warrants are,

- "1. Minimum Vehicular Volume. The warrant is satisfied when for each of any 8 hours of an average day the traffic volumes given in Table 23 exist on the major street and on the higher-volume minor-street approach to the intersection. The major-street and the minor-street volumes are for the same 8 hours. During those 8 hours the direction of higher volume on the minor street may be on one approach during some hours and on the opposite approach during other hours. When the 85-percentile speed of major-street traffic exceeds 40 miles per hour, or when the intersection lies within the built-up area of an isolated community having a population less than 10,000, the minimum vehicular volume warrant is 70 percent of the requirements below.

Table 23. Minimum Vehicular Volumes for Warrant 1

Number of lanes for moving traffic on each approach		Vehicles per hour on major street (total of both approaches)	Vehicles per hour on higher-volume minor-street approach (one direction only)
<u>Major Street</u>	<u>Minor Street</u>		
1	1	500	150
2 or more	1	600	150
2 or more	2 or more	600	200
1	2 or more	500	200

"2. Interruption of Continuous Traffic. The warrant is satisfied when for each of any 8 hours of an average day the traffic volumes given in Table 24 exist on the major street and on the higher-volume minor-street approach to the intersection, and the signal installation will not seriously disrupt progressive traffic flow. The major-street and minor-street volumes are for the same 8 hours. During those 8 hours the direction of higher volume on the minor street may be on one approach during some hours and on the opposite approach during other hours. When the 85-percentile speed of major-street traffic exceeds 40 miles per hour, or when the intersection lies within the built-up area of an isolated community having a population less than 10,000, the interruption of continuous traffic warrant is 70 percent of the requirements below.

"3. Minimum Pedestrian Volume. The minimum pedestrian volume warrant is satisfied when for each of any 8 hours of an average day the following traffic volumes exist:

1. On the major street 600 or more vehicles per hour enter the intersection (total of both approaches); or 1,000 or more vehicles per hour (total of both approaches) enter the intersection on the major street where there is a raised

Table 24. Minimum Vehicular Volumes for Warrant 2.

Number of lanes for moving traffic on each approach		Vehicles per hour on major street (total of both approaches)	Vehicles per hour on higher-volume minor-street approach (one direction only)
<u>Major Street</u>	<u>Minor Street</u>		
1	1	750	75
2 or more	1	900	75
2 or more	2 or more	900	100
1	2 or more	750	100

- median island 4 feet or more in width; and
2. During the same 8 hours as in paragraph 1 there are 150 or more pedestrians per hour on the highest volume crosswalk crossing the major street.

When the 85-percentile speed of major-street traffic exceeds 40 miles per hour, or when the intersection lies within the built-up area of an isolated community having a population of less than 10,000, the minimum pedestrian volume warrant is 70 percent of the requirements above.

"4. Progressive Movement. The progressive movement warrant is satisfied when:

1. On an isolated one-way street or on a street which preponderantly has unidirectional traffic significance, adjacent signals are so far apart that the desired degree of platooning and speed control of vehicles would otherwise be lost.
2. On a two-way street, adjacent signals do not provide the desired degree of platooning and speed control; and the proposed and adjacent signals can constitute a progressive signal system.

"5. Accident Experience. The accident-experience warrant is satisfied when:

1. Adequate trial of less restrictive remedies with satisfactory observance and enforcement has failed to reduce the accident frequency; and
2. Five or more reported accidents of types susceptible of correction by a traffic control signal have occurred within a 12-month period, each accident involving personal injury or property damage to an apparent extent of \$100 or more; and
3. There exists a volume of vehicular and pedestrian traffic not less than 80 percent of the requirements specified in the minimum vehicular-volume warrant, the interruption of continuous traffic warrant, or the minimum pedestrian-volume warrant; and
4. The signal installation will not seriously disrupt progressive traffic flow.

"6. Combinations of Warrants. Signals may occasionally be justified where no one warrant is satisfied but two or more are satisfied to the extent of 80 percent or more of the stated values. These exceptional cases should be decided on the basis of a thorough analysis of facts."

APPENDIX B
DATA

APPENDIX B

PART I: Intersection Locations

Table 25. Intersection Locations

Intersection Number	Location of Intersection	City
1	SR 662 (Lincoln Ave.) & Boeke Rd.	Evansville
2	SR 66 (Division St.) & New Green River Rd.	Evansville
3	SR 45 (5th St.) & Main St.	Rockport
4	Spring St. & St. Marys Ave.	Fort Wayne
5	US 27 (Lafayette St.) & Paulding Rd.	Fort Wayne
6	US 52 Bypass & Salisbury St. (County Farm Rd)	W. Lafayette
7	US 20 (McKinley Ave.) & Twyckenham Dr.	South Bend
8	SR 2 (Western Hwy) & Lombardy Ave.	South Bend
9	Old US 31 (Washington St.) & Lincoln Rd.	Kokomo
10	US 36 & SR 267	Avon
11	US 460, SR 62 (Chestnut St.) & Mulberry St.	Corydon
12	Georgetown Rd. & 34th St.	Indianapolis
13	Kessler & Rural St.	Indianapolis
14	US 421 (Market St.) & 4th St.	Monon
15	SR 38 (Main St.) & SR 1 (Sycamore St.)	Hagerstown
16	SR 49 (Calumet Ave.) & Evans Ave.	Valpariso
17	US 41 (Calumet Ave.) & 167th St.	Hammond
18	SR 73 (Broad St.) & 45th Ave. (Glen Park Rd.)	Griffith
19	US 40 (W. Main St.) & Franklin St.	Greenfield
20	US 40 (W. Main St.) & SR 13 (Broadway)	Greenfield
21	US 27 (13th St.) & US 224 (Nuttman Ave.)	Decatur
22	US 50, SR 37 (M St.) & 18th St.	Bedford
23	US 6 (New Ridge Rd.) & Lake Park Ave.	Hobart
24	Hanna St. & Pettit Ave.	Fort Wayne
25	McKinnie Ave. & Hanna St.	Fort Wayne
26	US 40 & Round Barn Rd.	W. of Richmond
27	SR 2, 49 (Lincolnway) & Garfield St.	Valpariso
28	US 50, SR 37 (L St.) & 13th St.	Bedford
29	SR 912 (Guthrie St.) & Lincoln St.	E. Chicago
30	SR 37 & SR 32, 38	E. of Noblesville

Table 25 (continued)

31	W. State Blvd. & St. Marys Ave.	Fort Wayne
32	SR 67 & Brown Rd. (Madison Ave.)	S. of Anderson
33	SR 13 (Anderson St.) & N. J St.	Elwood
34	SR 28 (State St.) & Broadway	Albany
35	SR 1 (Bluffton Rd.) & Ferguson Rd.	S. of Fort Wayne
36	US 27 (Lafayette St.) & Pettit Ave.	Fort Wayne
37	SR 9, 15, 37 (Baldwin Ave.) & Factory Ave.	Marion
38	SR 9, 15, 37 (Baldwin Ave.) & 4th St.	Marion

APPENDIX B

Part II: Intersection Traffic Data

Table 26. Intersection Traffic Data

Intersection Number	Signal Installation Year	Before Period	BEFORE VOLUME		
			Total Ave. ADT	Two-Way Major St. ADT	Larger Minor St. Entering ADT
1	1963	6/61-1/63	13,900	10,300	1,800
2	1963	1/62-8/63	13,500	7,700	3,000
3	1963	7/61-7/63	5,800	3,300	2,100
4	1963	9/61-7/63	9,800	7,300	1,300
5	1963	1/61-1/63	13,100	8,400	2,400
6	1962	1/60-1/62	14,200	11,800	1,600
7	1962	9/60-9/62	11,200	8,200	1,700
8	1962	1/60-1/62	12,400	9,800	2,100
9	1962	10/60-9/62	13,200	9,300	2,000
10	1962	10/60-10/62	8,500	6,500	1,100
11	1962	1/60-1/62	7,800	5,800	1,100
12	1961	1/60-4/61	7,000	3,900	1,700
13	1961	1/60-7/61	11,200	8,500	2,400
14	1961	1/59-7/61	5,800	4,300	800
15	1961	1/59-1/61	4,500	3,400	900
16	1961	1/59-1/61	12,200	9,900	1,300
17	1961	9/59-9/61	20,600	18,900	1,100
18	1961	1/59-1/61	12,400	7,100	2,800
19	1961	1/59-1/61	16,000	15,000	600
20	1961	1/59-1/61	16,900	15,600	1,000
21	1961	1/59-1/61	12,600	10,000	1,600
22	1960	1/58-1/60	14,200	12,000	1,400
23	1960	1/58-1/60	14,600	11,700	1,600
24	1960	1/58-1/60	7,400	4,900	1,600
25	1960	1/58-1/60	8,400	4,200	2,300
26	1959	1/57-1/59	15,600	14,400	800
27	1959	1/57-1/59	9,600	8,100	1,100
28	1959	1/57-1/59	13,500	11,200	1,300
29	1959	6/57-6/59	13,300	9,200	3,300
30	1959	1/57-1/59	8,800	4,800	2,200
31	1959	1/57-1/59	10,700	8,500	1,300
32	1958	1/56-1/58	14,300	9,000	3,200
33	1958	1/56-1/58	3,600	2,500	500
34	1958	1/56-1/58	4,700	4,000	300
35	1958	1/56-1/58	5,800	4,000	1,600
36	1957	1/56-4/57	13,400	9,700	2,300
37	1957	1/55-1/57	15,500	13,500	1,200
38	1956	1/54-1/56	20,300	18,900	800

Table 26. (continued)

Intersection Number	After Period	AFTER VOLUME			Traffic Growth Rate (Percent/Year)
		Total Ave. ADT	Two-way Major St. ADT	Larger Minor St. Entering ADT	
1	1/64-8/65	14,900	11,100	2,000	3.24
2	1/64-8/65	16,100	9,200	3,600	9.83
3	7/63-7/65	6,300	3,600	2,300	4.53
4	9/63-7/65	10,800	8,100	1,400	4.98
5	4/63-4/65	17,200	11,000	3,200	12.50
6	1/63-1/65	17,700	14,700	2,000	8.04
7	10/62-10/64	12,300	9,000	1,800	4.70
8	1/63-1/65	14,300	11,200	2,400	4.70
9	1/63-12/64	15,000	10,500	2,200	5.78
10	1/63-1/65	10,700	7,700	1,500	8.88
11	1/63-1/65	8,700	6,500	1,300	3.65
12	5/61-8/62	7,900	4,400	1,900	9.83
13	8/61-2/63	12,100	9,100	2,500	5.00
14	9/61-4/64	6,200	4,600	800	3.12
15	1/62-1/64	5,400	4,000	1,100	6.32
16	1/62-1/64	13,600	11,000	1,500	5.78
17	1/62-1/64	26,500	24,400	1,400	4.70
18	1/62-1/64	14,300	8,100	3,200	4.70
19	1/62-1/64	17,800	16,600	700	3.91
20	1/62-1/64	18,800	17,300	1,100	3.91
21	1/62-1/64	13,200	10,100	2,000	6.80
22	1/61-1/63	14,400	12,200	1,400	0.50
23	1/61-1/63	16,700	13,300	1,800	4.70
24	1/61-1/63	10,600	7,000	2,200	12.50
25	1/61-1/63	12,000	6,000	3,300	12.50
26	1/60-1/62	17,500	16,200	800	3.97
27	1/60-1/62	12,200	10,200	1,400	8.27
28	1/60-1/62	14,600	12,100	1,500	2.87
29	1/60-1/62	14,900	10,300	3,800	4.70
30	1/60-1/62	10,000	5,400	2,500	4.30
31	1/60-1/62	12,400	10,800	1,500	1.05
32	1/59-1/61	14,600	9,200	3,300	0.83
33	1/59-1/61	4,100	3,000	600	5.20
34	1/59-1/61	5,500	4,700	400	5.30
35	1/59-1/61	6,400	4,400	1,700	7.25
36	5/57-8/58	15,800	10,500	3,400	7.00
37	5/57-5/59	17,100	14,900	1,300	3.66
38	1/57-1/59	20,400	19,100	800	0.20

APPENDIX B

Part III: Intersection Accident Data

Part III: Intersection Accident Data

The following is the coding used in Table 27: The

Intersection Accident Data:

- FA: Number of accidents in which a fatality occurred.
- IA: Number of accidents in which an injury occurred but no fatalities occurred.
- VA: Number of accidents in which no fatalities or injuries occurred.
- TA: Total number of accidents, $TA = FA + IA + VA$.
- F: Total number of fatalities in all accidents.
- I: Total number of injuries in all accidents.
- V: Total number of vehicles in all accidents.
- L: Total number of accidents occurring in daylight.
- N: Total number of accidents occurring in dark.
- W: Total number of accidents occurring on wet pavement.
- D: Total number of accidents occurring on dry pavement.
- C: Total cost of all property damage, dollars.
- R-A: Right-angle accident.
- R-E: Rear-end accident.
- MISC: Miscellaneous accident.

Table 27. Intersection Accident Data

Intersection Number <u>1</u>	R-A		R-E		MISC	
	Before	After	Before	After	Before	After
FA	0	1	0	0	0	0
IA	2	4	1	1	1	1
VA	7	2	0	3	0	3
TA	9	7	1	4	1	4
F	0	1	0	0	0	0
I	4	6	1	1	1	1
V	18	14	2	8	3	8
L	5	4	1	3	1	4
N	4	3	0	1	0	0
W	5	3	1	2	0	0
D	4	4	0	2	1	4
C	2555	4950	1300	610	1000	920

Intersection Number <u>2</u>	R-A		R-E		MISC	
	Before	After	Before	After	Before	After
FA	0	0	0	0	0	0
IA	4	1	0	2	0	3
VA	17	2	2	9	3	12
TA	21	3	2	11	3	15
F	0	0	0	0	0	0
I	10	4	0	3	0	6
V	43	6	4	26	6	28
L	20	3	2	7	2	8
N	1	0	0	4	1	7
W	3	1	1	4	1	6
D	18	2	1	7	2	9
C	8020	975	330	3205	830	3805

Table 27. (continued)

Intersection Number <u>3</u>	R-A		R-E		MISC	
	Before	After	Before	After	Before	After
FA	0	0	0	0	0	0
IA	0	0	0	0	0	0
VA	1	0	0	0	2	5
TA	1	0	0	0	2	5
F	0	0	0	0	0	0
I	0	0	0	0	0	0
V	2	0	0	0	4	10
L	1	0	0	0	2	3
N	0	0	0	0	0	2
W	1	0	0	0	0	1
D	0	0	0	0	2	4
C	100	-	-	-	350	1175

Intersection Number <u>4</u>	R-A		R-E		MISC	
	Before	After	Before	After	Before	After
FA	0	0	0	0	0	0
IA	6	1	1	0	0	0
VA	7	5	0	1	1	1
TA	13	6	1	1	1	1
F	0	0	0	0	0	0
I	9	1	1	0	0	0
V	29	12	2	2	1	2
L	10	5	1	1	1	1
N	3	1	0	0	0	0
W	6	3	0	0	0	1
D	7	3	1	1	1	0
C	5455	1795	300	310	50	395

Table 27. (continued)

Intersection Number <u>5</u>	R-A		R-E		MISC	
	Before	After	Before	After	Before	After
FA	1	0	0	1	0	0
IA	4	3	0	2	0	2
VA	5	2	1	1	4	3
TA	10	5	1	4	4	5
F	1	0	0	1	0	0
I	13	4	0	6	0	3
V	22	12	2	9	8	10
L	8	3	1	2	1	4
N	2	2	0	2	3	1
W	3	0	0	0	0	1
D	7	5	1	4	4	4
C	7700	5725	135	2975	1630	2600

Intersection Number <u>6</u>	R-A		R-E		MISC	
	Before	After	Before	After	Before	After
FA	0	0	0	0	0	0
IA	2	3	1	3	2	4
VA	2	3	3	10	3	10
TA	4	6	4	13	5	14
F	0	0	0	0	0	0
I	3	4	1	5	2	6
V	8	12	8	26	7	27
L	4	5	3	7	4	11
N	0	1	1	6	1	3
W	2	2	2	10	1	4
D	2	4	2	3	4	10
C	1875	4360	1385	4105	4315	6180

Table 27. (continued)

Intersection Number <u>7</u>	R-A		R-E		MISC	
	Before	After	Before	After	Before	After
FA	0	0	0	0	0	0
IA	3	3	0	1	2	0
VA	10	3	0	3	1	2
TA	13	6	0	4	3	2
F	0	0	0	0	0	0
I	5	5	0	2	2	0
V	27	12	0	9	5	4
L	11	6	0	2	3	1
N	2	0	0	2	0	1
W	7	3	0	2	2	0
D	6	3	0	2	1	2
C	5200	2090	0	1330	575	475

Intersection Number <u>8</u>	R-A		R-E		MISC	
	Before	After	Before	After	Before	After
FA	1	0	0	0	0	0
IA	4	4	1	2	0	3
VA	3	6	2	9	1	12
TA	8	10	3	11	1	15
F	1	0	0	0	0	0
I	8	4	1	4	0	6
V	17	23	6	22	1	29
L	5	10	2	8	0	11
N	3	0	1	3	1	4
W	3	6	1	6	1	6
D	5	4	2	5	0	9
C	4830	5650	1205	5525	250	5375

Table 27. (continued)

Intersection Number <u>9</u>	R-A		R-E		MISC	
	Before	After	Before	After	Before	After
FA	0	0	0	0	0	0
IA	0	0	0	1	0	1
VA	2	3	1	3	1	5
TA	2	3	1	4	1	6
F	0	0	0	0	0	0
I	0	0	0	1	0	2
V	4	6	2	8	2	14
L	2	3	1	3	1	4
N	0	0	0	1	0	2
W	0	0	0	2	0	0
D	2	3	1	2	1	6
C	650	2125	275	1050	150	3775

Intersection Number <u>10</u>	R-A		R-E		MISC	
	Before	After	Before	After	Before	After
FA	0	0	0	0	0	0
IA	6	1	1	2	0	0
VA	7	1	2	6	4	5
TA	13	2	3	8	4	5
F	0	0	0	0	0	0
I	17	2	1	3	0	0
V	27	4	6	18	8	11
L	13	2	3	6	3	4
N	0	0	0	2	1	1
W	0	1	0	1	0	1
D	13	1	3	7	4	4
C	8290	2100	450	5350	945	3325

Table 27. (continued)

Intersection Number <u>11</u>	R-A		R-E		MISC	
	Before	After	Before	After	Before	After
FA	0	0	0	0	0	0
IA	0	0	0	0	0	0
VA	2	3	1	1	3	5
TA	2	3	1	1	3	5
F	0	0	0	0	0	0
I	0	0	0	0	0	0
V	4	6	3	2	6	10
L	1	2	0	0	3	3
N	1	1	1	1	0	2
W	0	0	1	0	0	1
D	2	3	0	1	3	4
C	900	875	400	150	285	1625

Intersection Number <u>12</u>	R-A		R-E		MISC	
	Before	After	Before	After	Before	After
FA	0	0	0	0	0	0
IA	1	0	0	0	0	1
VA	2	0	0	1	0	1
TA	3	0	0	1	0	2
F	0	0	0	0	0	0
I	2	0	0	0	0	1
V	7	0	0	3	0	3
L	3	0	0	0	0	1
N	0	0	0	1	0	1
W	0	0	0	1	0	1
D	3	0	0	0	0	1
C	1600	-	-	160	-	850

Table 27. (continued)

Intersection Number <u>13</u>	R-A		R-E		MISC	
	Before	After	Before	After	Before	After
FA	0	0	0	0	0	0
IA	1	0	0	1	1	0
VA	1	0	0	0	0	0
TA	2	0	0	1	1	0
F	0	0	0	0	0	0
I	4	0	0	2	2	0
V	4	0	0	2	2	0
L	2	0	0	1	1	0
N	0	0	0	0	0	0
W	0	0	0	0	0	0
D	2	0	0	1	1	0
C	850	-	-	100	1300	-

Intersection Number <u>14</u>	R-A		R-E		MISC	
	Before	After	Before	After	Before	After
FA	0	0	0	0	0	0
IA	0	0	0	0	0	1
VA	1	0	1	2	4	4
TA	1	0	1	2	4	5
F	0	0	0	0	0	0
I	0	0	0	0	0	1
V	2	0	2	4	8	10
L	0	0	1	1	2	4
N	1	0	0	1	2	1
W	1	0	0	1	2	1
D	0	0	1	1	2	4
C	65	-	115	175	1025	665

Table 27. (continued)

Intersection Number <u>15</u>	R-A		R-E		MISC	
	Before	After	Before	After	Before	After
FA	0	0	0	0	0	0
IA	0	0	0	1	0	0
VA	1	0	2	0	0	0
TA	1	0	2	1	0	0
F	0	0	0	0	0	0
I	0	0	0	1	0	0
V	2	0	4	2	0	0
L	1	0	2	1	0	0
N	0	0	0	0	0	0
W	1	0	0	0	0	0
D	0	0	2	1	0	0
C	50	-	950	450	-	-

Intersection Number <u>16</u>	R-A		R-E		MISC	
	Before	After	Before	After	Before	After
FA	0	0	0	0	0	0
IA	0	2	0	1	0	1
VA	5	3	0	7	5	7
TA	5	5	0	8	5	8
F	0	0	0	0	0	0
I	0	2	0	1	0	1
V	10	10	0	16	10	16
L	4	4	0	6	4	6
N	1	1	0	2	1	2
W	3	2	0	4	3	3
D	2	3	0	4	2	5
C	2025	1095	-	2750	1400	2555

Table 27. (continued)

Intersection Number <u>17</u>	R-A		R-E		MISC	
	Before	After	Before	After	Before	After
FA	0	0	0	0	0	0
IA	0	3	0	1	1	1
VA	1	2	4	6	4	5
TA	1	5	4	7	5	6
F	0	0	0	0	0	0
I	0	8	0	1	2	1
V	2	10	9	19	8	13
L	1	5	3	5	5	4
N	0	0	1	2	0	2
W	1	2	2	6	3	2
D	0	3	2	1	2	4
C	400	1330	925	2280	800	950

Intersection Number <u>18</u>	R-A		R-E		MISC	
	Before	After	Before	After	Before	After
FA	0	0	0	0	0	0
IA	0	1	0	6	1	1
VA	3	4	0	4	3	4
TA	3	5	0	10	4	5
F	0	0	0	0	0	0
I	0	1	0	9	2	1
V	6	10	0	22	7	9
L	2	1	0	8	1	2
N	1	4	0	2	3	3
W	2	1	0	5	3	1
D	1	4	0	5	1	4
C	480	3060	-	3425	1775	395

Table 27. (continued)

Intersection Number <u>19</u>	R-A		R-E		MISC	
	Before	After	Before	After	Before	After
FA	0	0	0	0	0	0
IA	0	2	0	3	0	2
VA	1	2	3	10	3	8
TA	1	4	3	13	3	10
F	0	0	0	0	0	0
I	0	4	0	4	0	3
V	2	8	6	27	6	19
L	1	4	3	11	3	6
N	0	0	0	2	0	4
W	0	1	2	7	2	6
D	1	3	1	6	1	4
C	400	3400	925	5255	925	2950

Intersection Number <u>20</u>	R-A		R-E		MISC	
	Before	After	Before	After	Before	After
FA	0	0	0	0	0	0
IA	1	0	0	2	2	3
VA	3	1	3	8	7	8
TA	4	1	3	10	9	11
F	0	0	0	0	0	0
I	2	0	0	2	2	3
V	8	2	6	20	18	22
L	4	0	2	7	6	9
N	0	1	1	3	3	2
W	3	1	0	5	4	3
D	1	0	3	5	5	3
C	2300	80	640	3395	2475	4855

Table 27. (continued)

Intersection Number <u>21</u>	R-A		R-E		MISC	
	Before	After	Before	After	Before	After
FA	0	0	0	0	0	0
IA	1	1	0	1	2	1
VA	6	2	3	8	5	4
TA	7	3	3	9	7	5
F	0	0	0	0	0	0
I	1	3	0	3	3	1
V	15	6	6	21	14	10
L	6	3	2	4	1	3
N	1	0	1	5	6	2
W	2	1	2	6	4	2
D	5	2	1	3	3	3
C	2435	1385	1150	2735	2155	1440

Intersection Number <u>22</u>	R-A		R-E		MISC	
	Before	After	Before	After	Before	After
FA	0	0	0	1	0	0
IA	0	0	0	1	0	0
VA	6	2	2	4	3	2
TA	6	2	2	6	3	2
F	0	0	0	1	0	0
I	0	0	0	1	0	0
V	12	4	4	12	6	4
L	5	2	1	6	3	2
N	1	0	1	0	0	0
W	3	1	1	0	0	1
D	3	1	1	6	3	1
C	740	910	255	1680	635	265

Table 27. (continued)

Intersection Number <u>23</u>	R-A		R-E		MISC	
	Before	After	Before	After	Before	After
FA	1	0	0	0	0	0
IA	2	1	0	4	2	2
VA	3	1	3	4	11	5
TA	6	2	3	8	13	7
F	1	0	0	0	0	0
I	2	2	0	4	2	2
V	12	4	6	16	28	14
L	5	1	2	5	7	4
N	1	1	1	3	6	3
W	2	1	2	1	4	4
D	4	1	1	7	9	3
C	3870	650	1065	2445	9025	2855

Intersection Number <u>24</u>	R-A		R-E		MISC	
	Before	After	Before	After	Before	After
FA	0	0	0	0	0	0
IA	4	2	0	1	0	0
VA	6	0	2	2	2	1
TA	10	2	2	3	2	1
F	0	0	0	0	0	0
I	7	4	0	1	0	0
V	20	5	4	6	3	1
L	9	2	2	3	2	0
N	1	0	0	0	0	1
W	2	1	2	2	2	0
D	8	1	0	1	0	1
C	4515	1950	370	270	220	300

Table 27. (continued)

Intersection Number <u>25</u>	R-A		R-E		MISC	
	Before	After	Before	After	Before	After
FA	0	0	0	0	0	0
IA	1	1	0	0	0	0
VA	8	0	0	1	0	0
TA	9	1	0	1	0	0
F	0	0	0	0	0	0
I	1	1	0	0	0	0
V	18	3	0	2	0	0
L	8	1	0	1	0	0
N	1	0	0	0	0	0
W	7	0	0	0	0	0
D	2	1	0	1	0	0
C	2070	800	-	445	-	-

Intersection Number <u>26</u>	R-A		R-E		MISC	
	Before	After	Before	After	Before	After
FA	0	0	0	0	0	0
IA	0	0	0	3	0	4
VA	3	0	2	5	3	1
TA	3	0	2	8	3	5
F	0	0	0	0	0	0
I	0	0	0	4	0	10
V	6	0	4	17	6	11
L	2	0	2	6	3	4
N	1	0	0	2	0	1
W	2	0	0	5	2	3
D	1	0	2	3	1	2
C	550	-	300	3200	1585	3225

Table 27. (continued)

Intersection Number <u>27</u>	R-A		R-E		MISC	
	Before	After	Before	After	Before	After
FA	0	0	0	0	0	0
IA	0	1	0	4	0	1
VA	2	7	0	8	6	6
TA	2	8	0	12	6	7
F	0	0	0	0	0	0
I	0	1	0	4	0	1
V	4	16	0	25	13	13
L	2	6	0	10	5	5
N	0	2	0	2	1	2
W	0	4	0	10	3	3
D	2	4	0	2	3	4
C	330	1640	-	3610	2130	805

Intersection Number <u>28</u>	R-A		R-E		MISC	
	Before	After	Before	After	Before	After
FA	0	0	0	0	0	0
IA	0	4	0	1	0	0
VA	2	1	1	1	4	0
TA	2	5	1	2	4	0
F	0	0	0	0	0	0
I	0	6	0	1	0	0
V	4	10	3	5	8	0
L	1	4	1	2	4	0
N	1	1	0	0	0	0
W	1	3	0	2	0	0
D	1	2	1	0	4	0
C	550	2085	500	440	2315	-

Table 27. (continued)

Intersection Number <u>29</u>	R-A		R-E		MISC	
	Before	After	Before	After	Before	After
FA	0	0	0	0	0	0
IA	2	2	0	0	1	3
VA	10	1	0	2	2	6
TA	12	3	0	2	3	9
F	0	0	0	0	0	0
I	3	2	0	0	1	3
V	25	6	0	6	5	18
L	9	2	0	2	3	5
N	3	1	0	0	0	4
W	5	0	0	1	1	2
D	7	3	0	1	2	7
C	3990	1150	-	1300	450	4100

Intersection Number <u>30</u>	R-A		R-E		MISC	
	Before	After	Before	After	Before	After
FA	1	2	0	0	0	0
IA	12	5	0	2	3	4
VA	7	1	3	4	3	2
TA	20	8	3	6	6	6
F	1	3	0	0	0	0
I	28	13	0	2	3	9
V	42	16	6	12	12	13
L	16	5	2	6	5	6
N	4	3	1	0	1	0
W	3	4	1	3	1	2
D	17	4	2	3	5	4
C	18,815	8575	910	2450	3835	4680

Table 27. (continued)

Intersection Number <u>31</u>	R-A		R-E		MISC	
	Before	After	Before	After	Before	After
FA	0	0	0	0	0	0
IA	1	1	0	0	1	0
VA	4	1	0	0	3	5
TA	5	2	0	0	4	5
F	0	0	0	0	0	0
I	2	1	0	0	1	0
V	10	4	0	0	8	10
L	5	2	0	0	3	5
N	0	0	0	0	1	0
W	0	0	0	0	1	1
D	5	2	0	0	3	4
C	2975	585	-	-	555	1470

Intersection Number <u>32</u>	R-A		R-E		MISC	
	Before	After	Before	After	Before	After
FA	0	0	0	0	0	0
IA	2	0	0	1	2	2
VA	3	1	0	6	3	3
TA	5	1	0	7	5	5
F	0	0	0	0	0	0
I	4	0	0	2	5	3
V	11	2	0	14	10	9
L	2	1	0	5	4	3
N	3	0	0	2	1	2
W	1	1	0	4	2	1
D	4	0	0	3	3	4
C	9950	250	-	4760	1105	3400

Table 27. (continued)

Intersection Number <u>33</u>	R-A		R-E		MISC	
	Before	After	Before	After	Before	After
FA	0	0	0	0	0	0
IA	2	0	1	1	0	0
VA	3	1	0	0	3	2
TA	5	1	1	1	3	2
F	0	0	0	0	0	0
I	4	0	3	2	0	0
V	11	2	4	2	6	4
L	2	1	1	1	3	2
N	3	0	0	0	0	0
W	1	1	0	0	0	1
D	4	0	1	1	3	1
C	3510	450	1700	210	305	755

Intersection Number <u>34</u>	R-A		R-E		MISC	
	Before	After	Before	After	Before	After
FA	0	0	0	0	0	0
IA	0	0	0	0	0	0
VA	0	0	0	0	4	4
TA	0	0	0	0	4	4
F	0	0	0	0	0	0
I	0	0	0	0	0	0
V	0	0	0	0	9	11
L	0	0	0	0	4	3
N	0	0	0	0	0	1
W	0	0	0	0	1	0
D	0	0	0	0	3	4
C	-	-	-	-	520	1345

Table 27. (continued)

Intersection Number <u>35</u>	R-A		R-E		MISC	
	Before	After	Before	After	Before	After
FA	0	0	0	0	0	0
IA	0	1	0	1	0	1
VA	1	1	1	3	2	2
TA	1	2	1	4	2	3
F	0	0	0	0	0	0
I	0	1	0	7	0	1
V	2	4	2	9	5	6
L	1	1	1	4	2	2
N	0	1	0	0	0	1
W	0	2	0	2	2	1
D	1	0	1	2	0	2
C	600	750	260	2040	1090	1600

Intersection Number <u>36</u>	R-A		R-E		MISC	
	Before	After	Before	After	Before	After
FA	0	0	0	0	0	0
IA	0	1	0	0	0	1
VA	3	2	1	2	1	4
TA	3	3	1	2	1	5
F	0	0	0	0	0	0
I	0	1	0	0	0	1
V	6	6	2	4	2	10
L	1	3	1	2	1	4
N	2	0	0	0	0	1
W	0	0	1	1	1	2
D	3	3	0	1	0	3
C	905	1210	180	115	100	1305

Table 27. (continued)

Intersection Number <u>37</u>	R-A		R-E		MISC	
	Before	After	Before	After	Before	After
FA	0	0	0	0	0	0
IA	0	1	0	0	1	0
VA	0	1	1	3	1	3
TA	0	2	1	3	2	3
F	0	0	0	0	0	0
I	0	2	0	0	1	0
V	0	4	2	6	4	6
L	0	2	1	3	0	3
N	0	0	0	0	2	0
W	0	1	1	1	0	1
D	0	1	0	2	2	2
C	-	475	750	800	850	535

Intersection Number <u>38</u>	R-A		R-E		MISC	
	Before	After	Before	After	Before	After
FA	0	0	0	0	0	0
IA	4	0	0	0	0	0
VA	1	2	0	5	2	2
TA	5	2	0	5	2	2
F	0	0	0	0	0	0
I	7	0	0	0	0	0
V	10	4	0	10	5	4
L	3	2	0	3	1	0
N	2	0	0	2	1	2
W	1	1	0	2	0	1
D	4	1	0	3	2	1
C	2370	425	-	1320	915	600

APPENDIX C
TRAFFIC VOLUME CALCULATIONS

APPENDIX C

TRAFFIC VOLUME CALCULATIONS¹

Because the signal installations were made several years, 1956 thru 1963, prior to this study, it was not possible to take volume counts of the traffic using the intersections at the times of signalization. Weekday intersection traffic counts, taken for less than twenty-four hours, that were made prior to signal installations; twenty-four hour weekday counts of the traffic volumes on the major roads throughout the state; and monthly, weekday, and area factors that are used to convert twenty-four weekday counts into average daily traffic (ADT) counts were obtained from the Division of Planning and the Division of Traffic Engineering of the Indiana State Highway Commission or the cities in which the intersections were located. This traffic volume information was used to develop an estimate of the traffic using each intersection during the before and after signalization periods by the following methods.

A traffic growth rate was calculated for each intersection by using two of these twenty-four hour weekday traffic counts made at the same location and the compound interest rate concept:

$$V = V_0 (1 + i)^n$$

- V: Volume count one.
- V_0 : Volume count two.
- n: Number of years between the two counts.
- i: Growth rate per year.

The location of the twenty-four hour weekday counts was not always at the intersection, but, if not, it was usually within three blocks of the intersection on the major street and reflected the traffic growth at the study intersection. The dates of the two counts were usually three to five years apart. The growth rates ranged from 0.2 to 12.5 percent per year.

The following is the procedure used to obtain an estimate of the ADT using each intersection for each year of the study periods:

$$T = \frac{A}{C} \cdot B \cdot K$$

- A: Volume of twenty-four hour weekday traffic on major road.
- B: Volume of weekday intersection traffic for hours 7-9 AM and 12-6 PM.
- C: Volume of twenty-four hour weekday traffic on major roads for hours 7-9 AM and 12-6 PM.
- K: Expansion factor for converting twenty-four hour weekday volume to ADT.
- T: Estimate of intersection ADT for the year in which the weekday intersection traffic count was made.

It was necessary to assume that the intersection hourly variation of the traffic did not change to make this estimate.

By using the growth rate previously calculated and the compound interest rate concept, estimates of the ADT were calculated for each year of the study period for each intersection. By knowing the exact number of days for the before and the after periods for each year of study, the total amount of traffic entering the intersection during each period was calculated.

APPENDIX D

CURVES FOR DETERMINING WHETHER A SIGNIFICANT CHANGE
IN ACCIDENTS OCCURRED AFTER A ROADWAY MODIFICATION
USING PROCEDURE 1

APPENDIX D
CURVES FOR DETERMINING WHETHER A SIGNIFICANT CHANGE
IN ACCIDENTS OCCURRED AFTER A ROADWAY MODIFICATION
USING PROCEDURE 1

For procedure 1 the before signalization estimate of the mean number of accidents occurring was used as though it were a constant value (11,16). Accident occurrence was considered to be Poisson distributed. The hypothesis tested was that the mean number of accidents in the after modification period was identical to the mean number of adjusted before period accidents.

For this test of hypothesis it must also be assumed that all other factors at the study site, the intersection in this study, remained constant from the beginning of the period in which the before modification accidents are collected to the end of the period in which the after accidents are collected. If some factor were not constant, then some adjustment must be made to account for its effects on the accidents.

To determine the increase or decrease in accidents needed to occur after the modification in order to have a significant change in the before number of accidents, it was necessary to establish the boundary values of the critical region of the Poisson distribution; this distribution

being based upon the number of accidents occurring during the after period. By calculating the boundary values of the critical regions of many Poisson distributions -- Poisson distributions for which the mean number of accidents varied from zero to 36, it was possible to construct the following curves, Figures 28, 29, 30, and 31.

To use these curves an example will be presented: Using Figure 28, assume that the average accident frequency before modification is 16, then the number of accidents needed to occur after the modification to have a significant decrease is 7 or less and to have a significant increase is 30 or more.

FIGURE 28. VALUES OF ACCIDENTS NEEDED TO OCCUR AFTER A MODIFICATION TO EXPERIENCE A SIGNIFICANT CHANGE IN ACCIDENTS (SIGNIFICANCE LEVEL : 1%)

FIGURE 29. VALUES OF ACCIDENTS NEEDED TO OCCUR AFTER A MODIFICATION TO EXPERIENCE A SIGNIFICANT CHANGE IN ACCIDENTS (SIGNIFICANCE LEVEL : 10%)

FIGURE 30. VALUES OF ACCIDENTS NEEDED TO OCCUR AFTER A MODIFICATION TO EXPERIENCE A SIGNIFICANT CHANGE IN ACCIDENTS (SIGNIFICANCE LEVEL : 15 %)

FIGURE 31. VALUES OF ACCIDENTS NEEDED TO OCCUR AFTER A MODIFICATION TO EXPERIENCE A SIGNIFICANT CHANGE IN ACCIDENTS (SIGNIFICANCE LEVEL : 30%)

APPENDIX E

COMPARISON OF TWO POISSON DISTRIBUTED OBSERVATIONS
USING PROCEDURE 2

APPENDIX E

COMPARISON OF TWO POISSON DISTRIBUTED OBSERVATIONS (2)
USING PROCEDURE 2

The number of adjusted before accidents is x_1 and the observed number of after accidents is x_2 . It is desired to test the hypothesis, using procedure 2, that the mean number of accidents for the before period population and for the after period population is the same, $H_0: \lambda_1 = \lambda_2 = \lambda$.

The exact test is as follows: Event one, E_1 , is identified with getting X_1 equal to x_1 and X_2 equal to x_2 . Event two, E_2 , is identified with getting $X_1 + X_2$ equal to $x_1 + x_2$. Then under the hypothesis,

$$\begin{aligned}
 \Pr \{E_1 \cap E_2\} &= \Pr \{X_1 = x_1, X_2 = x_2 \text{ and } X_1 + X_2 = x_1 + x_2\} \\
 &= \Pr \{X_1 = x_1, X_2 = x_2\} \\
 &= \Pr \{X_1 = x_1\} \Pr \{X_2 = x_2\} \\
 &= \frac{e^{-\lambda} \lambda^{x_1}}{x_1!} \cdot \frac{e^{-\lambda} \lambda^{x_2}}{x_2!} = \frac{e^{-2\lambda} \lambda^{x_1 + x_2}}{x_1! x_2!} .
 \end{aligned}$$

Using the Addition Theorem for the Poisson Distribution,

$$\Pr \{E_2\} = \Pr \{X_1 + X_2 = x_1 + x_2\} = \frac{e^{-2\lambda} (2\lambda)^{x_1 + x_2}}{(x_1 + x_2)!}.$$

Then using conditional probability, that

$$\Pr \{E_1 | E_2\} = \frac{\Pr \{E_1 \cap E_2\}}{\Pr \{E_2\}},$$

$$\begin{aligned} \Pr \{X_1 = x_1, X_2 = x_2 | X_1 + X_2 = x_1 + x_2\} &= \frac{\Pr \{E_1 \cap E_2\}}{\Pr \{E_2\}} \\ &= \frac{\lambda^{x_1 + x_2} (x_1 + x_2)!}{(2\lambda)^{x_1 + x_2} x_1! x_2!} = \binom{x_1 + x_2}{x_1} \left(\frac{1}{2}\right)^{x_1} \left(1 - \frac{1}{2}\right)^{(x_1 + x_2) - x_1} \end{aligned}$$

which is the $(x_1 + 1)$ th term in the binomial expansion for $n = x_1 + x_2$, and $\theta = 1/2$. The last equation gives the probability that $X_1 = x_1$, given that $X_1 + X_2$ equals $x_1 + x_2$. As in the Fisher exact test, it is desired to have all the probabilities for all values of X_1 more extreme than the observed value of x_1 . The sum of these probabilities is

$$\begin{aligned} \Pr \{X_1 \geq x_1 | X_1 + X_2 = x_1 + x_2\} \\ = \sum_{\nu=x_1}^{x_1+x_2} \binom{x_1 + x_2}{\nu} \left(\frac{1}{2}\right)^{\nu} \left(1 - \frac{1}{2}\right)^{x_1+x_2-\nu}. \end{aligned}$$

For the upper tail of a binomial distribution with $\theta = 1/2$ so that $\theta \div 1 - \theta = 1$, then

$$\begin{aligned} \Pr \{ X_1 \geq x_1 \mid X_1 + X_2 = x_1 + x_2 \} \\ = \Pr \left\{ F < \frac{x_1 + x_2 - x_1 + 1}{x_1} \right\} \\ = \Pr \left\{ F < \frac{x_2 + 1}{x_1} \right\} \end{aligned}$$

where F is used as the symbol for the F distribution which would have $2x_1$ and $2(x_2+1)$ degrees of freedom (22). The P value, the significance level, for a one-sided test against the alternate $\lambda_1 > \lambda_2$ is determined by

$$\Pr \{ F(2x_1, 2(x_2+1)) < \frac{x_2 + 1}{x_1} \} = P$$

and since $\Pr \{ F < F_p \} = P$

$$F_p(2x_1, 2(x_2+1)) = \frac{x_2 + 1}{x_1}$$

or

$$F_{1-p}(2(x_2+1), 2x_1) = \frac{x_1}{x_2 + 1}$$

For the two-tail test of $\lambda_1 = \lambda_2$ where P is the significance level, the upper tail critical value is $F_{1-P/2}(2(x_2+1), 2x_1)$ and is compared to the value of $\frac{x_1}{x_2+1}$.

The lower critical value is determined by $F_{P/2}(2x_1, 2(x_2+1))$ and is compared to $\frac{x_2+1}{x_1}$.

For example, if the number of before accidents, X_1 , is equal to 10 and the number of after accidents X_2 is equal to 4, at a significance level of P percent the upper critical value would be,

$$F_{1-P/2}(2(4+1), 2 \cdot 10) = F_{1-P/2}(10, 20)$$

and would be compared to $\frac{x_1}{x_2+1} = 2.00$. The lower critical value would be $F_{P/2}(20, 10)$ and would be compared to $\frac{x_2+1}{x_1} = 0.5$.

<u>Significance Level</u>	<u>$F_{1-P/2}$</u>	<u>$F_{P/2}$</u>
10%	.426	2.38
20%	.516	1.94

The change in the accidents is significant at a significance level of 20 percent but not 10 percent.

APPENDIX F

COLLISION DIAGRAMS FOR SELECTED INTERSECTIONS

APPENDIX F

COLLISION DIAGRAMS FOR SELECTED INTERSECTIONS

The meaning of the symbols used on the following collision diagrams is shown below:

<u>Symbol</u>	<u>Meaning</u>
Path of a moving vehicle
Path of a pedestrian or bicycle
Property damage only accident
Injury Accident
Fatal Accident
Parked Vehicle
Fixed Object
Vehicle backing
Vehicle out of control

4

NOTE: BEFORE-TWO WAY STOPS
ON NEW GREEN RIVER
ROAD
AFTER-TRAFFIC
SIGNALS

FIGURE 32. COLLISION DIAGRAM FOR SR 66 & NEW
GREEN RIVER ROAD (INTERSECTION 2)

FIGURE 33. COLLISION DIAGRAM FOR U.S. 52 BY-PASS & SALISBURY STREET (INTERSECTION 6)

4

NOTE : BEFORE-TWO WAY STOPS
ON TWYCKENHAM DR.
AFTER-TRAFFIC
SIGNALS

FIGURE 34. COLLISION DIAGRAM FOR U.S. 20 &
TWYCKENHAM DRIVE (INTERSECTION 7)

FIGURE 35. COLLISION DIAGRAM FOR SR 49 &
EVANS AVENUE (INTERSECTION 16)

FIGURE 36. COLLISION DIAGRAM FOR SR 67 &
 BROWN ROAD (INTERSECTION 32)