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SOME EFFECTS OF UNWARRANTED TRAFFIC SIGNALS

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PURDUE UNIVERSITY
INDIANA STATE HIGHWAY COMMISSION

Final Report

SOME EFFECTS OF UNWARRANTED TRAFFIC SIGNALS

TO: Harold L. Michael, Director
Joint Highway Research Project

September 5, 1979

Project: C-36-17NN

FROM: Harold L. Michael, Research Engineer
Joint Highway Research Project

File: 8-4-40

The attached report is a Final one on the JHRP Study titled "Some Effects of Unwarranted Traffic Signals". This Report has been authored by Mr. Chung-Cha Liu, Graduate Instructor in Research on our Staff, under the direction of Professor Harold Michael.

This Study evaluated the delays and accidents at ten (10) intersections where traffic signals were located but where doubt existed as to their being warranted or at intersections with STOP signs where traffic signals were being considered or authorized for installation. The results of the ten case studies in the Lafayette area indicated clearly that considerable delay and resulting excess fuel use resulted from unwarranted traffic signals. Conclusions were not obvious relative to accidents because of the relative rarity of accidents at low volume intersections.

The Study has generated much interest and the results should be valuable to those charged with the operation of our street and highway systems. The Report is submitted for acceptance of the Final Report, as having met the objectives of the Study.

Respectfully submitted,

Harold L. Michael
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Final Report
SOME EFFECTS OF UNWARRANTED TRAFFIC SIGNALS

by

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Joint Highway Research Project

Project No.: C-36-17NN

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TABLE OF CONTENTS, cont.

	Page
Intersection I: Grant Street and North Street	91
Intersection J: Salisbury Street and Stadium Avenue . . .	99
CHAPTER 5 - ACCIDENT ANALYSIS	107
Intersection A: 4th Street and Brown Street	109
Intersection B: Union Street and 6th Street	113
Intersection C: Union Street and 26th Street	116
Intersection D: Teal Road and 30th Street	119
Intersection F: Indiana State Road 26 and Creasy Lane . .	122
Intersection G: Wiggins Street and Salisbury Street . . .	125
Intersection H: Fowler Avenue and Salisbury Street . . .	128
Intersection I: Grant Street and North Street	128
Intersection J: Salisbury Street and Stadium Avenue . . .	133
Accident Evaluation Analysis	137
CHAPTER 6 - RECOMMENDATIONS AND CONCLUSIONS	145
Warranted Controls at the Study Intersections	145
Intersection A: 4th Street and Brown Street	145
Intersection B: Union Street and 6th Street	146
Intersection C: Union Street and 26th Street	146
Intersection D: Teal Road and 30th Street	146
Intersection E: State Street and Airport Road	146
Intersection F: S.R. 26 and Creasy Lane	147
Intersection G: Wiggins Street and Salisbury Street and	
Intersection H: Fowler Avenue and Salisbury Street .	147
Intersection I: Grant Street and North Street . . .	147
Intersection J: Salisbury Street and Stadium Avenue .	148
Conclusions	148
Unwarranted Signal Installations	148
Concluding Remarks	150
Recommended Additional Research	151
LIST OF REFERENCES	152

LIST OF TABLES

Table	Page
1. Two-Way, Two-Lane Intersection Delay at 100 VPH Side Street Volume	12
2. Field Test Results of TOL Strategy	16
3. Accident Effect Produced by Signalization of Two-Way and Four-Way STOP-Controlled Intersections	19
4. Intersection Accidents and Accident Costs by Control Devices	21
5. List of Study Locations in Indiana	25
6. Standard NETSIM Statistical Output	36
7. Summary of Vehicle Counts - Intersection A, October 1978	45
8. Average Travel Time and Average Delay by Approach and by Turning Movement - Intersection A (Traffic Signal)	47
9. Summary of Vehicle Counts - Intersection B, October 1978	50
10. Average Travel Time and Average Delay by Approach and by Turning Movement - Intersection B (Traffic Signal)	52
11. Summary of Vehicle Counts - Intersection C, October 1978	55
12. Average Travel Time and Average Delay by Approach and by Turning Movement - Intersection C (Traffic Signal)	57
13. Summary of Vehicle Counts - Intersection D, August 1978 .	59
14. Average Travel Time and Average Delay by Turning Movement for the Minor Street - Intersection D (STOP Sign)	60
15. Average Travel Time in Seconds under Different Inter- section Control Devices - Intersection D	62
16. Estimated 1978 Travel Delay in Vehicle-Hours for the STOP Sign and Semi-Actuated Signal Controls - Intersection D	64

LIST OF TABLES, cont.

Table	Page
17. Summary of Vehicle Counts - Intersection E, October 1977	68
18. Average Delay per Vehicle by Approach and by Turning Movement - Intersection E (Four-Way STOP)	70
19. Average Travel Time in Seconds under Different Intersection Control Devices - Intersection E (Peak Hours)	73
20. Average Travel Time in Seconds under Different Intersection Control Devices - Intersection E (Off-Peak Hours)	74
21. Estimated 1978 Travel Delay in Vehicle-Hours for Three Different Intersection Controls - Intersection E	76
22. Summary of Vehicle Counts - Intersection F, October 1977	78
23. Average Travel Time and Average Delay by turning Movement for the Minor Street - Intersection F (STOP Sign)	79
24. Average Travel Time in Seconds under Different Intersection Control Devices - Intersection F	82
25. Estimated 1978 Travel Delay in Vehicle-Hours for the STOP Sign and Full-Actuated Signal Controls - Intersection F	83
26. Summary of Vehicle Counts - Intersection G, April 1978	87
27. Summary of Vehicle Counts - Intersection H, April 1978	88
28. Average Travel Time and Average Delay by Approach and by Turning Movement - Intersection G and H (STOP Sign)	90
29. Summary of Vehicle Counts - Intersection I, October 1978	93
30. Average Travel Time in Seconds under Different Intersection Control Devices - Intersection I	96
31. Estimated 1978 Travel Delay in Vehicle-Hours for the Two-Way STOP and Traffic Signal Controls - Intersection I	98
32. Summary of Vehicle Counts - Intersection J, October 1978	100

LIST OF TABLES, cont.

Table	Page
33. Average Travel Time and Average Delay by Turning Movement for the Minor Street - Intersection J (STOP Sign) . .	102
34. Average Travel Time in Seconds under Different Intersection Control Devices - Intersection J	105
35. Estimated 1978 Travel Delay in Vehicle-Hours for the STOP Sign and Semi-Actuated Signal Controls - Intersection J .	106
36. Accident Summary - 4th Street and Brown Street	112
37. Accident Summary - Union Street and 6th Street	115
38. Accident Summary - Union Street and 26th Street	118
39. Accident Summary - Teal Road and 30th Street	121
40. Accident Summary - S.R. 26 and Creasy Lane	124
41. Accident Summary - Wiggins Street and Salisbury Street . .	127
42. Accident Summary - Fowler Avenue and Salisbury Street . .	130
43. Accident Summary - Grant Street and North Street	132
44. Accident Summary - Salisbury Street and Stadium Avenue . .	135
45. Cost in Dollars per Accident at Four Percent Discount Rate	139
46. Severity Rates and Accident Evaluation Indexes by Urban and Rural Accident Types	140
47. Accident Evaluation (as Represented by Figure of Merit) of the Study Intersections	143

LIST OF FIGURES

Figure	Page
1. Schematic Diagram Showing a Typical Intersection Layout for Data Collection	27
2. Field Form for Travel Time Study	29
3. NETSIM Model System	34
4. Intersection Modeled for NETSIM Simulation	41
5. Relative Location of Intersection D	65
6. Physical Layout of Intersection G and H	85
7. Physical Layout of Intersection I	92
8. Collision Diagram - Intersection A	110
9. Legend to Collision Diagram	111
10. Collision Diagram - Intersection B	114
11. Collision Diagram - Intersection C	117
12. Collision Diagram - Intersection D	120
13. Collision Diagram - Intersection F	123
14. Collision Diagram - Intersection G	126
15. Collision Diagram - Intersection H	129
16. Collision Diagram - Intersection I	131
17. Collision Diagram - Intersection J	134

ABSTRACT

Liu, Chung-Cha. M.S.C.E., Purdue University, August 1979. The Effect of Unwarranted Traffic Signals. Major Professor: Harold L. Michael.

Although the traffic signal is recognized as a very desirable traffic control device where experience and engineering studies shows it is warranted, many traffic signals have been placed at intersections where they result in great delay and much waste of fuel. The proper control device at such intersections is most likely the STOP sign on the minor street. Furthermore many ill-advised individuals continue to pressure for more traffic signals with the belief that they are the solution to all traffic and accident problems.

The objective of this study was to provide traffic engineers with factual evidence of the detrimental impacts which occur when traffic signals are installed before they are required. A total of ten intersections from the Greater Lafayette area were studied. They included three signalized intersections and seven STOP sign controlled intersections. The performance of each study intersection was examined and evaluated with respect to travel delay through the intersection and accident frequency. A simulation package, NETSIM, was also employed at some of the intersections to investigate the performance of traffic flow under different types of intersection controls.

It was found that unwarranted traffic signals invariably increase the total intersection delay. At three unwarranted signalized locations,

cumulative travel delay ranging from 3200 to 4200 vehicle-hours were wasted in 1978 by the major-street traffic. Whereas at another study intersection, the conversion from traffic signal control to two-way STOP control saved 10,340 vehicle-hours in 1978 without any accident increase. Of the 10,340 vehicle-hours saved, approximately 30 percent of them were by the minor-street traffic.

CHAPTER 1 INTRODUCTION

Much recent attention has been directed toward means of reducing the national consumption of rapidly depleting energy resources. Studies have shown that transportation is responsible for 24 percent of the total domestic demand for energy, and that 95.7 percent of that energy for transportation comes from petroleum sources (1). Fast-rising expenditure outlays for foreign oil coupled with growing user demand have intensified efforts to increase the efficiency of the existing highway system. In this connection signalized intersections, the major source of delay, congestion, and accident exposure have been studied comprehensively.

Admittedly, signalized control at intersections has been one of the most effective ways of traffic control for decades. It is reported that about 5,000 signals have been installed each recent year in the United States, and the number of signalized intersections is increasing at a rate of about three percent annually (2). These figures include those at warranted locations as well as some at unwarranted ones. For the warranted intersections, no substitute has proved to be more efficient than signals. For unwarranted signal installations, other methods of control--usually STOP signs on the minor street--are considered superior but little research which documents the disbenefits of signals has been performed.

In general, the application of traffic control signals should be based upon a comprehensive investigation of traffic and roadway conditions in relation to the eight warrants contained in the Manual on Uniform Traffic Control Devices (MUTCD) (3). However, in many communities, a lack of traffic engineering expertise, or political pressure, or both, frequently result in unwarranted signal installations. An even worse aspect is the general public's belief that traffic control signals provide the solution to all traffic problems at intersections. This has consequently led to their installation at a large number of locations where no legitimate warrant exists.

In spite of relatively high capital and maintenance costs, some or all of the following disbenefits often result from an unwarranted signal installation:

- 1) Excessive delay may be caused.
- 2) Unnecessary stoppings and speed changes result in much waste of fuel and increased emission of air pollutants.
- 3) Disobedience of the signal indications may be encouraged.
- 4) Accident frequency (especially the rear-end type) can be significantly increased.
- 5) The use of less adequate routes may be encouraged in an attempt to avoid such signals.

Perhaps the most significant of the above listed resulting characteristics are those of increased delays, accidents and fuel use.

Purpose and Scope of the Study

As previously noted, very little effort has been applied to correlate intersection delay and accident frequency with unwarranted traffic control signals. In recognition of this, the primary purpose of this research project was to provide traffic engineers with factual evidence of the detrimental impacts which occur when traffic signals are installed before they are required. Specifically, the scope of the study included the following:

- 1) A quantitative assessment of the travel times and delays through similar intersections with two types of control, STOP signs or unwarranted signals.
- 2) A comparison between the respective travel times to determine any significant differences among the two control types studied.
- 3) An examination of the differences in the level of safety provided by the two control types. The level of safety was measured in terms of actual accidents over a three year period.

It was anticipated that the findings of this research would assist traffic engineers in arriving at a decision on whether to install a signal, discontinue a signal or revise the mode or hours of operation and other features of intersection control. The general public should also be made aware of the findings of this research as it will be of direct benefit to motorists.

CHAPTER 2 BACKGROUND INFORMATION

In this chapter definitions of the various traffic engineering elements involved in the study are reviewed. In addition, a literature review of previous studies in the area of STOP sign and signal controlled intersections is also presented.

Definitions

Traffic control devices are defined in the 1965 Highway Capacity Manual as "any sign, signal, marking, or device placed or erected for the purpose of regulating, warning, or guiding vehicular traffic and/or pedestrians" (4). The traffic control signal and traffic sign are described separately in the same manual as follows:

"Traffic Control Signal--Any device, whether manually, electrically, or mechanically operated, by which traffic is alternately directed to stop and permitted to proceed."

"Traffic Sign--A traffic control device mounted on a fixed or portable support which conveys a specific message by means of words or symbols, and is officially erected for the purpose of regulating, warning, or guiding traffic."

Traffic signs that are commonly used at local unsignalized intersections are YIELD and STOP signs. Only the STOP sign, however, is of interest and studied in this research.

Traffic Control Signal

A variety of types of traffic signal controllers are utilized, their complexity depending on the purpose they serve. They include "(a) pretimed traffic signal control, in which fixed time signal cycles are established in accordance with predetermined time schedules; and (b) traffic-actuated signal control, in which the intervals are varied in accordance with actuation of demand-detecting devices by vehicles and sometimes also by pedestrians" (5).

The actuated signal control is generally divided into two basic types--namely, semi-traffic-actuated control, in which means are provided for actuation by traffic on one or more, but not all, approaches, and full-traffic-actuated control, in which means are provided for actuation by traffic on all approaches. A variety of detecting devices is used, ranging from simple installations that register only the presence or nonpresence of vehicles on an approach, to complex volume-density equipment in which detector actuations by individual vehicles on each approach, or each lane of each approach, are received, stored, and interpreted.

In the case of an isolated intersection with signals, the controller serves simply to allocate the total time available proportionately to the two highways crossing at the particular location, with due consideration to the relative traffic demands and the available pavement widths on the several legs. In many urban areas it is desirable to interconnect groups of closely-spaced signals in order to facilitate traffic flow along substantial lengths of an arterial or throughout an entire network of streets. Control of

such interconnection ranges from simple linkage of a few signals under one master controller to computer control of the entire signal system of a city.

Because the principal function of traffic signals is to permit crossing streams of traffic to share the same intersection by means of time separation, the major criterion for signal control is the volume of traffic entering the intersection. Generally, traffic control signals are not needed if traffic is sufficiently light that adequate gaps appear at frequent enough intervals to permit all intersecting traffic to enter and cross intersection with little delay. The need for a traffic control signal at any particular location must, however, be carefully evaluated in relation to several warrants. Eight warrants are given in the 1978 Manual on Uniform Traffic Control Devices for Streets and Highways (MUTCD) for signal installation. The titles of these warrants are presented below (6):

- Warrant 1 Minimum vehicular volume
- Warrant 2 Interruption of continuous traffic
- Warrant 3 Minimum pedestrian volume
- Warrant 4 School crossing
- Warrant 5 Progressive movement
- Warrant 6 Accident experience
- Warrant 7 Systems
- Warrant 8 Combination of warrants

No attempt will be made here to discuss in detail these warrants. The MUTCD should be consulted for such discussion.

A signalized intersection which fails to meet at least one of the warrants, no matter when the signal was installed, is thus referred to as an "unwarranted signalized intersection". Consequently, the

traffic control signals that were placed at an unwarranted signalized intersection are "unwarranted signals". These terms are used throughout this study and no additional explanation is given in the following chapters.

Although warrants in the MUTCD represent the best currently available guidelines in the determination of the need for traffic control signals, it must be noted that in no case should they be considered as absolute criteria. Professional judgement based on experience and consideration of all related factors must be used in conjunction with warrants in arriving at a decision on signal installation.

STOP Sign

At unsignalized intersections, "the STOP sign serves two purposes--safety and facilitation of traffic movement" (7). The warrants for the STOP sign as listed by the MUTCD are given below (8):

- 1) Intersection of a less important road with a main road where application of the normal right-of-way rule is unduly hazardous.
- 2) Street entering a through highway or street.
- 3) Unsignalized intersection in a signalized area.
- 4) Other intersections where a combination of high speed, restricted view, and serious accident record indicates a need for control by the STOP sign.

The MUTCD also specifies as to where STOP signs should not be used. The main points mentioned in this connection are summarized below (9):

- 1) On through roadways of an expressway, STOP signs should never be used.
- 2) At a signalized intersection, STOP signs should not be erected.
- 3) STOP signs should normally be installed on the minor street to stop the lesser flow of traffic at an intersection. Posting of STOP signs on the major street to control the major flow should only be done if it is justified by traffic engineering studies.
- 4) Erection of temporary or part time STOP signs should never be done for other than emergency purposes.
- 5) Use of STOP signs should not be for controlling the speed of vehicles.

STOP signs may be two-way or multiway depending on traffic conditions at the intersection. Generally two-way STOP controls are used to make vehicles on a minor road give right-of-way to the vehicles on an intersecting major street. A four-way STOP is used when the volumes of the intersecting roads are in balance and the total vehicular volume entering the intersection from all approaches averages at least 500 vehicles per hour for any eight hours of an average day. When traffic signals are warranted and urgently needed, four-way STOP is also used as an interim measure that can be installed quickly to control traffic while arrangements are made for the signal installation.

Literature Review

A literature review was conducted to evaluate the state-of-the-art in the area of measurement and evaluation of the traffic characteristics associated with STOP and traffic signal controlled intersections. In the following paragraphs a brief summary of the literature review is presented.

Delay and Travel Time

The delay literature review may be broadly considered in three parts. First are field studies, second are theoretical studies, and third is combination of field and theoretical work to develop computer simulation programs.

Field measurements were made by Volk at eight intersections (10). These had two- and four-way STOP, fixed-time or actuated signals at various times. A method of measuring stopped (waiting time) delay was developed, utilized a metronome and hand computer. A 5½-hour period of delay data was gathered at each location.

Volk plotted average delay against major street volumes for several groups of intersections, and developed linear regression lines with coefficients of correlation ranging from 0.68 to 0.91. Plots against minor volumes correlated at the 0.25 to 0.60 levels. The much higher correlation when using major route volumes as the variable has also been reported by other authors.

Volk also observed that signalization of a four-lane by two-lane intersection with high entering volumes in all lanes increased total delay about five times over that associated with STOP sign

control on the two-lane street. Conversion of a two-lane by two-lane intersection from four-way STOP to signal control reduced total delay. The total volumes in this case, however, were low and the result should not be considered as a typical case.

Raff studied side street delays under two-way STOP for main street volumes up to 900 VPH (11). Side street volumes varied from zero to 510 VPH. He defined a delayed car as (a) having a lag shorter than the Critical Lag (the time between vehicles on the major street an average motorist needs to cross), or (b) not a first position car. A formula for percentage of vehicles delayed under these conditions was then developed. The formula does not, however, consider distance to the next signalized intersection on the main street (platoon effect) nor the number of main or side street lanes.

The proposed warrant for STOP sign installation by Raff's study was that at least 50 percent of the minor street vehicles during the eight highest hours would be delayed. He further postulated that such a warrant involved numbers of cars, while total time of delay might be more appropriate. He was unable to establish a direct relationship between volumes and delay.

Several methods of collecting field delay data have been developed (12). Berry measured stopped-time delay at three-phase signalized intersections, comparing traffic-actuated with fixed-time control (13). He found that the average delay per vehicle was 44 percent less with actuated control than with the fixed-time signal; a decrease of 3.3 seconds per vehicle.

Comparison with Raff's STOP sign data at equivalent total hourly volumes indicated somewhat higher total delay would be produced by a signal. More definite comparisons of course require measurements at the same or equivalent intersections, such as the referenced work by Volk.

Berry also measured the delay effect at intersections about $\frac{1}{4}$ mile apart. He found both peak hour and off-peak delays, with coordinated fixed-time signals, to be less than one-half that produced by operating independent actuated signals without coordination.

Hall studied delay under four-way STOP and under semi-actuated control (14). Only two approaches (one on each street) were checked and thus complete intersection values could not be calculated. Based on the data, he concluded the particular conditions at the site resulted in ten percent higher overall delay under signal control.

Bleyl developed average delay curves for minor street flows of 100 to 200 VPH versus major flows of zero to 1200 VPH for intersections of two-way, two-lane streets, with bypassing of left turn vehicles, allowed on the shoulder (15). The intersection was studied under two-way STOP and under optimized split, fixed-time signal control. The computed delay values for typical volume combinations are shown in Table 1.

Bleyl also compared delay values under signal control to the flashing specification values in the 1961 MUTCD. This was a recommendation to flash fixed-time signals when volumes fall below 50 percent of minimum levels for any four or more consecutive hours. He concluded that the 50 percent value was probably low.

TABLE 1 : TWO-WAY, TWO-LANE INTERSECTION DELAY AT 100 VPH SIDE STREET VOLUME

MAJOR STREET VOLUME	VEHICLE HOURS DELAY	
	TWO-WAY STOP	SIGNAL
200	.19	.25
400	.28	.25
600	.47	.28
800	.70	.31
1000	1.20	.42
1200	1.90	.55

SOURCE : REFERENCE (15)

Kell also simulated traffic at two-way, two-lane type intersection (16). He produced numerous curves from which side street delay, major street delay, and total delay values can be extracted. The study showed the low amount of side street delay associated with two-way STOP control compared with a nearly threefold increase in total delay if the intersection is signalized. It also showed for the same conditions, that signalization was found to increase the side street delay by 40 percent. It significantly increased the percentage of vehicles delayed.

Lewis and Michael simulated a 44-foot major arterial without parking intersecting with a 40-foot side street allowing parking (17). Simulation was for STOP control on the minor street or for semi-actuated signal control on the same street. They calculated lines of equal delay for the side-street related to major-street volumes, for two Critical Lag times (4.8 and 5.8 seconds) and for two detector spacings (21 and 150 feet). Using a 5.8 second Lag and a 150-foot detector location, total delay for a signalized intersection was calculated to be more than under two-way STOP for the following volume combinations:

- 1) Side street up to 150 VPH versus main street up to 1050 VPH.
- 2) Side street up to 200 VPH versus main street up to 950 VPH.
- 3) Side street up to 300 VPH versus main street up to 650 VPH.
- 4) Side street up to 350 VPH versus main street up to 500 VPH.

Delay has been used as a value in several economic studies.

Ruiter and Shuldiner used operating costs based on fuel and time as

inputs to the Lewis simulation program (18). Dale also developed cost data including delay for STOP sign and signal control (19).

A NCHRP study was conducted on the comprehensive evaluation of traffic signs at intersections (20). The main objective of the NCHRP study was to develop a procedure that could be used to determine the best possible type of control for an intersection under given conditions. Controls were recommended for consideration based on priority and continuity of traffic flows. In situations where more than one control type qualified for further consideration after meeting system requirements, the final selection was recommended to be made on the basis of an index of individual intersection operation. This index was derived by predicting delay and accident experience under each of the control types under consideration.

A recent European study developed a self-optimizing control strategy named Traffic Optimization Logic (TOL) for isolated traffic signals (21). The basic criterion used is to minimize total vehicle delay at a given traffic demand. In this TOL method, the decision to extend a phase is made at regular intervals by the examination of a control function. This function represents the difference in vehicle-seconds of delay between the gain made by the extra vehicles that can pass the intersection during an extension and the loss of the queuing vehicles in the cross street resulting from that extension.

Both simulation work and field tests were done to compare TOL with conventional fixed-time and vehicle-actuated controls. The results indicated strongly that TOL strategy gives substantial

reductions of average delay and proportion of stopped vehicles. Table 2 gives the field tests results from the study. The difference in mean delay for vehicles are significant at the 0.01 level. The difference for bus delay between TOL and the other methods is also significant.

Safety Characteristics

The effect of signalization on traffic operations and safety has been widely reported. However, the results of these studies vary considerably and research shows situations in which total accidents have decreased and other situations in which total accidents have increased.

An early comprehensive study of the effect of signalization on intersection accidents included data on 599 intersections in 24 cities (22). Vey found that signalization of an intersection with three or less accidents per year, increased the frequency 39 to 70 percent. If the frequency was over three, accidents were decreased by 19 to 49 percent by signalization. He also found signals to increase rear-end accidents by 37 percent, but to decrease right angle types by 56 percent. Vey further found a straight line trend of accident increase with hourly volumes, under non-signal control. With signalization, the curve flattened with increased volume. At average total entering volumes of 900 VPH (for the 12 highest hours), every signalized intersection showed a decrease in accidents.

Another report covered 39 intersections which had been signalized in urban and rural areas of Michigan (23). Accidents increased an

TABLE 2 : FIELD TEST RESULTS OF TOL STRATEGY

VARIABLE	TRAFFIC	CONTROL MODE		
		FIXED-TIMED	VEHICLE-ACTUATED	TOL
TRAFFIC FLOW, H	AUTOS	2600	2740	2620
	BUSES	18	12	20
AVERAGE DELAY, S	AUTOS	21.5 + 0.9	20.2 + 3.0	15.5 + 0.4
	BUSES	20.4 + 2.0	20.0 + 3.0	12.2 + 1.2
PROPORTION STOPPED, %	AUTOS	68	67	59
	BUSES	63	62	55

NOTE : LIMITS REFER TO THE 95 PERCENT CONFIDENCE INTERVAL

SOURCE : REFERENCE (21)

average of 23 percent, with the greatest percentage occurring at the simpler intersection types such as T and undivided cross. Injuries decreased 20 percent, however, and fatalities dropped 50 percent.

The Michigan data were also grouped according to the five intersections having greater than an ADT average of 20,200 and the eight having entering volumes below this average. The accident rate increased from 1.72 to 2.27 (32 percent) by signalization of the lower volume intersections. It decreased slightly however, from 1.31 to 1.29 (two percent) at the above-average-volume intersections.

An Ohio study included 65 rural intersections which had been signalized (24). Average entering ADT was 11,000. When intersections were grouped by volume, the accident rate per million entering vehicles decreased 10 percent at the 36 below-average-volume locations. The accident rate increased 27 percent at the 29 above-average-volume intersections. The report concluded that traffic signals lose their ability to reduce accidents somewhere in the range of ADT 9600 to 11,000.

A study of minor improvement projects in California found overall accident rate reductions averaging 39 percent when traffic signals were installed at 32 locations (25). In another study on 125 California locations where new signals were installed during 1964, it was found accidents were reduced at 61 percent of the intersections (26).

Schoene's study in Indiana is one of the most significant (27). Accident trends were analyzed at 38 intersections where controls were changed from STOP signs to traffic signals. The intersections were mixed urban, suburban, and rural. The tabulation was limited to

accidents occurring within 200 feet of the intersections. Data tested for statistical significance according to three general accident classifications are shown in Table 3.

Schoene further found that 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 offset the decrease in right angle accidents, and a decrease in total accidents thus occurred.

Considering severity rates for all intersections, he found little difference to occur. When there was a significant change, it was an increase with signalization.

A study of accidents as related to type of signal controller was reported by the Oregon Highway Department (28). A suburban intersection on a four-lane highway was studied for five years with semi-actuated control and two years with volume-density (full-actuated) control. Accidents on the highway occurring within 150 feet of the intersection were checked. The average annual number of rear-end accidents was reduced by 62 percent after the change to full-actuated operation.

The flashing operation of traffic signals during off-peak hours was also studied (29). A staff report by the District of Columbia concluded that regular 24-hour "stop-and-go" operation of traffic signals is safer than a flashing operation during night hours. Accidents decreased an average of 40 percent at the 162 locations during the period when full operation was substituted for night flashing. Injury accidents were reduced by 50 percent and right angle accidents by 60 percent during the period previously controlled by flashing.

TABLE 3 : ACCIDENT EFFECT PRODUCED BY SIGNALIZATION OF TWO-WAY AND FOUR-WAY STOP-CONTROLLED INTERSECTIONS

ORIGINAL CONTROL AND NUMBER OF LOCATIONS	PERCENT OF INTERSECTIONS BY ACCIDENT TYPE			
	RIGHT ANGLE	REAR-END	OTHER	OVERALL
TWO-WAY STOP, 32 INTERSECTIONS				
INCREASE	3	37	19	19
NO SIGNIFICANT CHANGE	88	63	81	81
DECREASE	9	0	0	0
FOUR-WAY STOP, 6 INTERSECTIONS				
INCREASE	0	17	17	17
NO SIGNIFICANT CHANGE	50	83	83	50
DECREASE	50	0	0	33

SOURCE : REFERENCE (27)

Work has been performed in the area of accident costs by Wilbur Smith in the Washington, D.C. area (30). The study was based on involvements rather than complete data for each accident. Data from Table 42 of the Smith report, allowed computation of various percentages, as shown in Table 4.

Accidents at intersections have been examined and classified by severity of damage. The most common breakdown is by proportion of fatal, bodily injury, and property damage. Abramson utilized the results of statewide accident studies conducted in Illinois (1958), Massachusetts (1953), New Mexico (1955), and Utah (1956) to establish a rate of severity tabulated by accident type (31). An accident evaluation index and accident evaluation factors are then computed by using percentage distribution of accidents by types, that is, pedestrian, right angle, rear-end, left-turn, and all others. The accident evaluation factors are multipliers that, when applied to an accident history profile for an intersection, yields a single figure of merit.

TABLE 4 : INTERSECTION ACCIDENTS AND ACCIDENT COSTS BY CONTROL DEVICES

CONTROL DEVICES	PERCENTAGE OF ALL INVOLVEMENTS	PERCENTAGE OF COST
SIGNALS	46.4	41.9
STOP SIGNS	30.1	32.9
YIELD SIGNS	5.6	4.8
OTHER SIGNS	1.4	2.5
NO CONTROL	16.5	17.9
TOTAL	100.0	100.0

SOURCE : REFERENCE (30)

CHAPTER 3 STUDY METHODOLOGY

Basically an intersection should be capable of facilitating traffic flows efficiently and safely. Efficiency most usually is judged with respect to the capability to minimize delay whereas safety is inherently reflected by the accident history. In fact, delay also includes speed changes and stopping of vehicles at intersections. Thus additional consumption of fuel and increased emission of pollutants are caused in addition to the time loss. In this study, the evaluation of the performance of the sample intersections was carried out by analysis of overall travel time and accident history as well as on site observations of traffic flow and if any, pedestrian crossings.

Study Location

As stated by the title of this study, the main purpose was to evaluate traffic signal control which is not warranted. It was decided to restrict the selection of intersections to the Lafayette-West Lafayette area in order to make its conduct practical relative to time and to reduce the cost of the study. It was recognized, however, that the Greater Lafayette area with a population exceeding 75,000 is a typical medium-sized community in the state of Indiana. The results from this study is thus believed to be representative of and/or applicable to other urban or suburban areas.

As the first step of site selection, a relatively accurate map of the Lafayette area was used and all traffic signal controlled intersections were located on it. Effort was then directed to the identification of two particular types of intersections, namely, intersections of two collector streets and intersections of a collector street and a minor arterial, as it was most likely that unwarranted traffic control signals would be found at such locations. Seven intersections of these two types were found.

In the second step, field trips were made to verify on site the suitability of the selected intersections with respect to physical features, traffic conditions, and satisfaction of traffic signal warrants. Only three intersections were considered to have unwarranted signalization in this step and were thus included in the research.

For the third step, information was obtained from the Indiana State Highway Commission (ISHC) concerning five intersections in the Lafayette area where traffic control signals may soon be located. The existing control devices at these intersections are two-way STOP signs except for one which has four-way STOP signs. These locations offered a very good opportunity to investigate intersection performance in the transition stage between signal and STOP sign control. Their inclusion in the study also compensated for the small sample size of unwarranted signalized intersections that were available in the Lafayette area.

In the final step, two intersections located in the city of West Lafayette were also included in this study. One was the intersection of Grant Street and North Street. The control device there

had recently been changed from a regular "stop-and-go" signal to flashing STOP with flashing red indication facing North Street. The justification of making this conversion was studied. The other intersection was Salisbury Street and Stadium Avenue. A citizen organization had long criticized the flashing two-way STOP control at this intersection for safety reasons. Studies were done and appropriate control is suggested in the latter part of this report.

Ten intersections were studied in this research and a brief description of each intersection location is given in Table 5.

Data Collection

At every intersection a condition diagram was prepared before the start of the study. These diagrams are scale drawings showing the layout, widths, and grades of intersecting roadways, the locations of any intersection view obstructions (man-made or natural), traffic control devices, and parking practices. They not only provided useful information throughout the study but also served as a vital part of the accident analysis.

The types of data that were collected in the study included travel times, traffic volumes, turning movements, and accident records. In the following paragraphs the collection procedures are presented.

Travel Times

In this study, instead of directly measuring delay, travel time through an intersection was measured. The travel time was defined as the time taken by a vehicle to travel a given distance from a point

TABLE 5 : LIST OF STUDY LOCATIONS IN INDIANA

INTERSECTION	MAJOR ROAD	MINOR ROAD	LOCATION	TYPE OF CONTROL	INTERSECTION CONFIGURATION
A	4TH STREET (S.R. 43/ U.S. 231)	BROWN STREET	LAFAYETTE CITY	SIGNAL	RIGHT ANGLE
B	UNION STREET	6TH STREET	LAFAYETTE CITY	SIGNAL	RIGHT ANGLE
C	UNION STREET	26TH STREET	LAFAYETTE CITY	SIGNAL	T-INTERSECTION
D	TEAL ROAD (S.R. 25)	30TH STREET	LAFAYETTE CITY	TWO-WAY STOP	T-INTERSECTION
E	STATE STREET (S.R. 26)	AIRPORT ROAD (S.R. 526)	TIPPECANOE COUNTY	FOUR-WAY STOP*	RIGHT ANGLE
F	S.R. 26	CREASY LANE	TIPPECANOE COUNTY	TWO-WAY STOP	RIGHT ANGLE
G	WIGGINS STREET (U.S. 231)	SALISBURY STREET	WEST LAFAYETTE CITY	TWO-WAY STOP	RIGHT ANGLE
H	FOWLER AVENUE	SALISBURY STREET	WEST LAFAYETTE CITY	TWO-WAY STOP	RIGHT ANGLE
I	GRANT STREET	NORTH STREET	WEST LAFAYETTE CITY	TWO-WAY STOP*	OFFSET INTERSECTION
J	SALISBURY STREET	STADIUM AVENUE	WEST LAFAYETTE CITY	TWO-WAY STOP*	RIGHT ANGLE

* : WITH FLASHING CONTROL BEACON

prior to an intersection to another point beyond the intersection. The distance used as a "trap" for obtaining travel time was determined by the following method.

It was acknowledged that normal acceleration and deceleration rates for passenger cars are 3.3 and 4.6 miles per hour per second respectively (32). According to these figures, the distance needed for a vehicle with approaching speed 30 miles per hour to come to a full stop is 150 feet, whereas 200 feet is needed to bring a stopped vehicle to a running speed of 30 miles per hour. Assuming an average maximum queue length of 200 feet at an intersection approach during a peak period, the "trap" should originate at a point at least 350 feet ($200 + 150$) before an intersection where the average running speed on the roadway is reduced because of the presence of the intersection. The "trap" terminates at a point at least 200 feet after the intersection where the average running speed on the roadway is again reached. In this study, the minimum trap distance used was 350 feet on each leg of an intersection measured from the intersecting curbs. In figure 1, a typical intersection layout is shown schematically. It also should be noted here, that the previous assumption of 30 miles per hour running speed was considered to be a reasonable value for urban area and the trap distance so derived was large enough to cover the so called "zone of influence" of an intersection.

At every intersection, a clearly visible and suitable fixed object along the roadside (such as a utility pole, traffic sign, etc.)

FIGURE 1 : SCHEMATIC DIAGRAM SHOWING A TYPICAL INTERSECTION LAYOUT FOR DATA COLLECTION

was then selected to mark the trap end or beginning on each leg. The trap distance was measured using a measuring wheel and should be longer than 350 feet as noted earlier. However, difficulty did arise when a short block failed to accommodate a 350 feet distance. In this situation, the maximum possible distance was used.

For this study, the Floating-Car Method was chosen as the most practical method for measuring travel time through an intersection. Field data were collected by a two-man team using two stop watches. The driver operated the test car to repeatedly and at random enter a platoon of vehicles approaching an intersection and to remain within the platoon until a point beyond the intersection. During periods when the test car was not influenced by other vehicles, the driver observed the speed limit. The observer in the car used one stop watch to record the travel time for each test run. Whenever the vehicle was forced to stop, the duration of this stop was measured with the second stop watch. The field sheet used in this study is presented as Figure 2.

Studies have shown that from six to twelve runs must be made for accuracy of the order of ten percent in estimating the average travel time (33). Thus, in this study, at least six and up to twelve vehicle runs were made for each vehicle movement (straight through, right turn, or left turn) from an approach and for every approach of the intersection. Furthermore, an error tolerance of four seconds with an accompanying 90 percent probability level of not exceeding the error tolerance was used as a criterion to determine the additional number of test runs or sample size needed beyond the six minimum runs. For

TRAVEL TIME AND DELAY STUDY

TEST CAR TECHNIQUE

FIELD SHEET

INTERSECTION: _____ AND _____

TRIP STARTED AT _____ LEG OF _____

TRIP ENDED AT _____ LEG OF _____

IT IS A _____ MOVEMENT, TRIP LENGTH _____

RUN NO.	DATE	WEATHER	START TIME	TRAVEL TIME	STOPPED TIME
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					

COMMENTS _____

RECORDER _____

FIGURE 2 : FIELD FORM FOR TRAVEL TIME STUDY

signal controlled intersections, in some cases however, even twelve vehicle runs failed to obtain an average travel time with error less than the tolerance value of four seconds. This was recognized as associated with the large variation in stopped times associated with signalized intersections. For the other intersections that were controlled by STOP sign, the results were satisfactory.

The data collection was performed on weekdays between 7:00 a.m. and 6:00 p.m., and during clear, dry weather conditions. Trips were made during both peak and off-peak hours to insure a variation in traffic volumes. Throughout the study period, every attempt was made to collect travel time data that might be influenced by the intersection control device rather than by other characteristics such as a parking vehicle.

Traffic Volumes and Turning Movement Counts

Recent traffic volume information on five of the study intersections was available from the Indiana State Highway Commission (ISHC). For the others, volume counts were made using volume recorders with paper tape recording and pneumatic road tubes. The counts were made during weekdays and under dry, normal weather conditions. For each intersection, the counts covered at least a continuous 48-hour period.

Separate turning movement counts were made for each intersection in three one-hour periods namely, 7:30-8:30 a.m., 1:30-2:30 p.m., and 5:00-6:00 p.m. Several push button type counters mounted on a board were used to record volumes of various movements. Pedestrian movements were also recorded at one of the study intersections where a relatively high pedestrian volume existed.

Accident Records

The information regarding accidents at the study intersections was obtained from records kept by the Police Departments of West Lafayette, Lafayette and also from records kept by the Indiana State Police. In this study accident records for 1976 to 1978 were considered. This information was collected from the respective Police Department by searching accident record sheets in original or in microfilm.

Traffic Simulation Models

Computer simulation has become an important tool for traffic engineers and transportation planners. Field traffic data is expensive to obtain and it takes many hours of work to collect relevant information. On the other hand, a well-calibrated simulation model can yield an enormous amount of data quickly and inexpensively. For example, several months of real traffic observation are necessary to evaluate the effects of even simple changes in signal systems. But traffic simulation experiments are comparatively cheap and quick and they can be employed without liability associated with "playing around" with traffic signals.

In this study, an effective computer model was selected and four isolated stop sign controlled intersections were simulated under traffic signal control to evaluate the effect of control alternatives on traffic operation.

Selection of a Traffic Simulation Model

Numerous models have been developed in the past by individuals exploring the relationships characterizing traffic movements. A detailed evaluation of these existing simulation programs indicated that the best choice would be to adopt the simulation package developed under the auspices of the Federal Highway Administration as part of the Urban Traffic Control System implemented in Washington, D.C. (34,35). The model UTCS-1S, smaller version of the program UTCS-1 (known now as NETSIM), has a demonstrated flexible, modular format permitting its efficient application to a wide variety of traffic system problems. A chief factor influencing its selection over others was the model's national recognition as a widely validated traffic simulation model. Utilization of a well tested routine would lend further credence to the analysis results.

Purpose, Structure, and Operation of NETSIM

Designed as a medium for testing network control strategies, NETSIM offered the flexibility of examining schemes ranging from unsignalized, no sign control through dynamically-controlled traffic signal systems. The program also has the capability to simulate bus transit, pedestrian interference, mixed vehicular flows, and other items relevant to traffic engineering studies.

The NETSIM model is based, in part, on two earlier formulations: the "DYNET" model and the "TRANS" model. All three models describe a street network in terms of a series of interconnected links and

nodes, along which traffic is processed in a series of short time-steps subject to the imposition of varying forms of traffic control.

The NETSIM model is divided into three major parts or primary overlays called into execution by a main program. The three components, presented in Figure 3, perform virtually as separate, individual units. The first unit, called the Pre-Processor, is designed to simplify the process of preparing and checking data inputs. It performs numerous diagnostic checks on the incoming data files, orders the file, and prints out the relevant data describing the network to be simulated. The second unit "NETSIM Simulator" contains the main simulation program. It consists of 60 separate routines, which may be linked together in a variety of optional configurations depending on the requirements of the user. Post-Processor is the third unit which consists of a set of standard data manipulation and evaluation routines designed to operate on the outputs of the main simulation program to compare the results of two or more simulation runs.

In order to run the model, a street network is first broken down into a set of uni-directional links and nodes. Each link represents one direction of travel along one street between two adjacent intersections and each link may contain up to five moving lanes. Mid-block changes in geometry are accommodated by breaking a single block down into two or more successive links. Actual operation of the model proceeds in one second time steps. Vehicles enter the network via a series of "entry" links or from "source" nodes located within the body of the network proper. Each vehicle has

FIGURE 3 : NETSIM MODEL SYSTEM

Source: Reference (35)

associated with it a detailed "vehicle array" which is updated every time step. Containing a record of the vehicle's performance as it moves through the network, the array is initialized at the time of vehicle creation by probabilistically assigning a vehicle type (car or truck) and driver characteristic code. This random code is used to access various distributions such as the driver's amber phase response and gap acceptance. Other portions of the vehicle array are changed at the start of a new link. These values indicate the vehicle's lane assignment, desired free speed, and turning maneuver at the next intersection. A similar "link array" is maintained containing various parameters detailing operations on each link during the simulation period. It is updated at the end of each time step.

An "initialization period" is needed before the actual simulation to fill the network with cars. The program checks for equilibrium by comparing the balance of traffic entering and leaving the network. If equilibrium is obtained within the user specified maximum initialization time, the program will automatically terminate initialization. Otherwise, a warning message will be printed to that effect, and the model will abort.

Various measures of effectiveness are displayed at desired intermediate times and at the conclusion of the simulation interval. The output parameters, listed in Table 6, describe the cumulative performance of traffic on all links from start to finish of that interval.

TABLE 6 : STANDARD NETSIM STATISTICAL OUTPUT

1.	LINK IDENTIFICATION
2.	TOTAL VEHICLES MILES OF TRAVEL
3.	COUNT OF VEHICLES DISCHARGED FROM LINK
4.	TOTAL VEHICLES MINUTES OF TRAVEL TIME
5.	TOTAL DELAY TIME
6.	RATIO OF MOVING TIME TO TOTAL TRAVEL TIME
7.	TOTAL TRAVEL TIME TO DATE FOR LINK
8.	AVERAGE TRAVEL TIME PER VEHICLE
9.	AVERAGE DELAY TIME PER VEHICLE
10.	AVERAGE DELAY TIME PER VEHICLE MILE
11.	AVERAGE TRAFFIC SPEED
12.	AVERAGE LINK OCCUPANCY
13.	AVERAGE NUMBER OF STOPS PER VEHICLE
14.	AVERAGE SATURATION PERCENTAGE
15.	CYCLE FAILURE

SOURCE : REFERENCE (35)

Past Modification for the NETSIM Model

A previous study conducted by Hall had used NETSIM to investigate the effects of the type of control on various parameters associated with traffic flow through unsignalized intersection (36). In his study, the Post-Processor overlay was removed from the UTCS-1S version and thus all statistical testing must be completed exogenously to the simulation runs. Removal of this overlay was but the first of several subsequent changes made to UTCS-1S.

The second change was made to UTCS-1S in order to provide a capability to output the time-velocity history of minor autos traversing a specified observation area, assign a model year to the minor road autos, and model stop, yield or no sign controls.

The third change was to incorporate the Environmental Protection Agency's Automobile Exhaust Emission Modal Analysis Model directly into the UTCS-1S simulation as an additional overlay or subroutine. The result was an automated analysis tool capable of not only simulating traffic but also analyzing the subsequent velocity profiles to produce emission and fuel information.

Recent study by Radwan made further modification to the NETSIM model (37). His study presented a set of guidelines for traffic control at isolated intersections on high-speed rural highways. Changes were made mainly to provide the model with the capability to simulate traffic through rural divided highway intersections with different median widths and median openings. Modifications was also made in order to generate traffic conflict data at intersections.

Validation of the NETSIM

The NETSIM model has been widely verified against field data collected during previous studies. It has demonstrated a consistent and intuitively realistic behavior in response to various input conditions. A brief summary of the highlights of past validation efforts is presented below.

A comprehensive effort consisted of simulating a 16-block grid network located in downtown Washington, D.C. (38). Field data collected by means of a combination of aerial and ground-base time-lapse photographs were compared against simulation results. The model accurately reproduced the A.M. peaks traffic condition but exhibited some difficulty simulating the off-peak patterns. The model tended to overestimate vehicular speed and underestimate the total delay resulting in field to model differences of 16.8 to 21.8 percent. The major conclusion drawn was that the model performs more accurately given relatively disciplined as opposed to undisciplined flow.

Another study used NETSIM to evaluate the signal control schemes obtained from two optimizing routines, TRANSYT and SIGOP (39). Testing a network in San Jose, California, NETSIM demonstrated the superiority of the TRANSYT-derived signal settings in producing consistently lower delays and higher average speeds than the equivalent settings developed by SIGOP. This study illustrated the utility of NETSIM as a tool in evaluating various timing plans and providing quantitative performance information.

A Virginia study concerned an analysis conducted on the south-bound approach to the intersection of 23rd and US 1 in Arlington (40).

Stopped and aggregate delay data was tabulated during one 40 minute and two one-hour periods split into subintervals. Each subinterval was replicated fifteen times by the NETSIM model and the delay measures compared against the field data. A two sided Student's t test found NETSIM and the field values to be in close agreement at five percent significance level in 12 out of the 16 subintervals.

Another study in Oakland, California involved stop delay data collected at the intersection of Alcatraz and Shattuck (41). Field data were compared with simulation results from three models: NETSIM, a model by Lewis and Michael (42), and one by Wagner and Gerlough (43). Eleven 15 minute periods were collected for the signalized intersection and ten replications for each subinterval were generated by the three computer programs. NETSIM exhibited significantly different stop delay values for only ten out of 44 intervals. The comparison further substantiated the credibility of the NETSIM routine.

However, in addition to the extensive NETSIM testing that concentrated on signal controlled traffic networks, studies also documented the validity of the simulation under condition of unsignalized flow. Hall conducted verification experiments to test the performance of the NETSIM model in reproducing two-way STOP, YIELD, and no control vehicular behavior (44). A significant level of five percent found no significant difference between the observed and simulated travel times in all three control types studied.

Past validation projects such as these examples permitted the NETSIM model to be utilized in this study with a high degree of

confidence. The routine exhibits wide flexibility and a sufficient degree of accuracy to encourage its use as a traffic engineering aid. Proven to correspond closely to effects actually observed, the simulation technique offers a reasonable alternative to investigate intersection performance under different control devices.

Typical Intersection Latout for Simulation

In this study, the adopted layout for simulating intersection traffic is schematically illustrated in Figure 4. This simple network consists of the central intersection of interest and four surrounding dummy intersections. The dummy intersections are controlled by 80-second signals that always remain green. Nodes numbered greater than or equal to 800 are either an upstream node of an entry link or a downstream node of an exit link.

Initially, the network was modeled simply as four entrance links (shown as 800-6, 802-7, 804-8, and 806-9) feeding four approach links. Study of the output revealed that the entry links serve only as auto storage areas until the auto is emitted into the network. Intermediate links (6-2, 7-3, 8-4, and 9-5) were then inserted to permit the autos to accelerate to their probabilistically determined free speeds before coming under the influence of the main intersection, denoted as Node 1.

FIGURE 4 : INTERSECTION MODELED FOR NETSIM SIMULATION

CHAPTER 4 TRAVEL TIME-DELAY ANALYSIS

Admittedly, intersections probably account for more than three-fourths of all delays experienced in urban areas. Early in the literature review stage, strong indications were found that a travel time or delay evaluation might represent the most meaningful of all traffic signal measurements. As Lewis and Michael state: "Delay was a most important factor in the determination of volume warrants. From an economic viewpoint, the type of control device preferred is one that results in the minimum delay to motorists. Total or overall delay is the type of delay that has the greatest significance when comparing different types of intersection control. Total delay encompasses any delay as caused by the existence of traffic control devices and interaction with other vehicles. An undelayed straight through vehicle will pass through the intersection area at its desired speed. An undelayed turning vehicle will decelerate to a safe turning and then regain its desired velocity. Any travel time in addition to these requirements is considered a delay." (45)

In this chapter, each of the ten study locations was analyzed individually as a separate case. For the purpose of computing delay in this study, six to twelve (sometimes even more) random floating-car travel time runs were made through the trap area for each movement from each approach during peak and off-peak hours. Average travel times for peak and off-peak periods for each movement were the means of all

pertinent runs. An average undelayed travel time for each movement for peak and off-peak periods was the mean of all pertinent runs in which no stopped time delay (time spent in travel of three miles per hour or less) was encountered. Average delay per vehicle then was considered to be the difference between the calculated average travel time and the average undelayed travel time. This, of course, gives a conservative (too small) value for average delay per vehicle but was felt to be a realistic and certain way of calculating delay for each movement under varying volumes of traffic.

Before discussing the travel time-delay analysis, however, it should be pointed out that delay is only one of several factors to be considered in evaluating the efficiency or effectiveness of traffic controls at an intersection. Other factors include the following:

- 1) Motorists' desires -- motorists may prefer one type of control even though the average delay per vehicle is greater. For example, they may prefer the certainty of right-of-way provided by a signal even though delay at some intersections is lower when STOP signs are used.

- 2) Comparative accident experience is also an important factor in selecting type of intersection control. This is discussed in Chapter 5.

- 3) Use of traffic actuated equipment may have a psychological advantage since many motorists feel that they have a part in causing the signal to change to green (46).

- 4) Other factors include costs of equipment and its maintenance, and comparative costs of vehicle operation.

Intersection A: 4th Street and Brown Street

This simple 90-degree intersection is located near the Lafayette downtown area. The major street (4th) which is part of U.S. 231 and Indiana State Road 43 is a two-lane one-way street that serves north-bound traffic through the downtown area. The intersecting minor street (Brown) is a two-lane two-way street and was used to carry traffic across the Wabash River before the Brown Street Bridge was removed. The traffic volume on Brown Street decreased considerably after the removal of the bridge. Table 7 shows the October 1978 average hourly volumes on both streets. The average daily traffic (ADT) on 4th Street was 8235 and on Brown Street, 753--a volume split of approximately 90-10.

The existing control devices at the intersection consist of a two-phase pretimed traffic signal with cycle length of 55 seconds and WALK-DONT WALK pedestrian signals. In addition, NO TURN ON RED signs were installed on the south approach of 4th Street and on the east approach of Brown Street.

An examination of Table 7 indicates that no traffic signal warrant was met according to the 1978 MUTCD. Traffic volume on Brown Street was too low whereas volume on 4th Street was not high enough to justify a traffic signal. Field observations of pedestrian movement did not warrant any signal installation either. Furthermore, it was found that there was no interconnection between this traffic signal and the traffic signal located two blocks upstream (approximately 600 feet) at the intersection of 4th Street and Ferry Street.

TABLE 7 : SUMMARY OF VEHICLE COUNTS - INTERSECTION A, OCTOBER 1978*

HOUR BEGINNING AT	4TH STREET	BROWN STREET		HOUR ENDING AT
	SOUTH LEG**	EAST LEG	WEST LEG	
12AM	123	4	1	1A
1A	49	3	1	2A
2A	33	3	0	3A
3A	28	1	0	4A
4A	61	1	0	5A
5A	92	1	0	6A
6A	356	15	3	7A
7A	501	35	9	8A
8A	483	49	12	9A
9A	462	34	10	10A
10A	446	32	14	11A
11A	533	36	15	12A
12A	536	41	20	1P
1P	502	43	14	2P
2P	529	41	9	3P
3P	597	55	22	4P
4P	747	40	24	5P
5P	640	48	19	6P
6P	449	24	2	7P
7P	267	17	1	8P
8P	269	14	2	9P
9P	242	16	3	10P
10P	167	6	2	11P
11P	123	7	4	12P
TOTAL	8235	566	187	TOTAL

* : AVERAGE DAILY TRAFFIC AS ESTIMATED FROM A THREE-DAY 24-HOUR COUNT DURING THE MONTH

** : ENTERING VOLUME FROM SOUTH LEG

Average travel time and average delay that were gathered by the floating-car method are presented in Table 8. As expected, delays during peak hours were larger than those during off-peak hours. However, for the minor street (Brown), this difference was not great and in all cases was less than 15 percent. On the other hand, delay increased considerably during peak periods for the traffic on 4th Street. For example, a through vehicle suffered delay increase from 8.5 to 12.1 seconds, an increase of 42 percent. Also noted was that through traffic on all three approaches had longer delay than turning traffic did. The reason behind this was that trap length of through movement was longer than that of turning movement. Because of physical limitation (short block distance), the trap lengths used were relatively short and were not able to cover the entire deceleration and acceleration distance needed for a vehicle. Thus, longer trap length incurred longer delay.

Several field trips were further made to observe the traffic condition at the study location. It was found that in the afternoon peak period, after passing through and possibly stopping at the intersection of 4th Street and Ferry Street, traffic queued on the south approach of the study intersection waiting for a green light while nearly no traffic was present on Brown Street. In addition, the prohibition of right turn on red added even more delay to right turn vehicles as well as through vehicles.

From the above discussion, a two-way STOP sign may be a better control device over the existing traffic signal. This would result in no delay for the traffic on 4th Street which accounts for 90 percent of the total entering volume. Considering only the 12-hour period in

TABLE 8 : AVERAGE TRAVEL TIME AND AVERAGE DELAY BY APPROACH AND BY TURNING MOVEMENT - INTERSECTION A (TRAFFIC SIGNAL)

APPROACH	MOVEMENT	TRAP LENGTH (FEET)	PEAK HOURS			OFF-PEAK HOURS		
			AVERAGE TRAVEL TIME (SECONDS)	AVERAGE UNDELAYED TRAVEL TIME (SECONDS)	AVERAGE DELAY PER VEHICLE (SECONDS)	AVERAGE TRAVEL TIME (SECONDS)	AVERAGE UNDELAYED TRAVEL TIME (SECONDS)	AVERAGE DELAY PER VEHICLE (SECONDS)
4TH STREET SOUTH LEG	STRAIGHT	568	27.6	15.5	12.1	23.0	14.5	8.5
	R.T.	527	30.5	20.0	10.6	27.8	18.8	9.0
	L.T.	532	29.9	20.5	9.4	28.8	20.5	8.3
BROWN STREET EAST LEG	STRAIGHT	563	31.6	18.9	12.7	30.8	18.3	12.5
	R.T.	539	34.6	22.2	12.4	33.0	21.9	11.1
BROWN STREET WEST LEG	STRAIGHT	563	37.5	18.8	18.7	35.1	18.5	16.3
	L.T.	544	35.3	21.3	14.0	34.2	21.3	12.9

the day time in which the travel time data was collected, the estimated yearly travel time savings under STOP sign control would have been about 4200 vehicle-hours in 1978. For the minor street, no significant increase would be expected. Even in the peak hour, the average arrival rate on the minor approach was less than one vehicle per minute. Drivers would have no problem in finding sufficient gaps to cross the major street because traffic on 4th Street moves as a platoon due to the upstream traffic signal.

Further consideration was also given to the fire department that is located at the southeast corner of the intersection. The question was: should the signal be retained as an emergency traffic signal for the fire department? The answer was no. According to section 4E-19 of the MUTCD, an emergency traffic signal may be justified if the stopping sight distance for vehicles approaching on the through street is insufficient to permit safe entrance of emergency vehicles. At this study intersection, the fire department has no direct access to the major street (4th) and field observation also indicated an adequate stopping sight distance for the one-way traffic on 4th Street at the intersection.

Intersection B: Union Street and 6th Street

This signalized intersection is located in the City of Lafayette. The major street (Union) is a two-lane one-way street that serves east-bound traffic through the city. A parallel one-way street one block away (Salem Street) carries westbound traffic and the two streets change into a two-lane two-way street near the intersection with 21st

Street. The minor street (6th) which is a two-lane two-way street carries traffic between a residential area and the downtown business area. It ends about one-half mile north of the intersection. The average hourly volumes in October 1978 on both streets are tabulated in Table 9. The ADT on Union Street was 12,637 and on 6th Street, 3209 -- a volume split of 80-20.

Some other physical conditions of the intersection have to be mentioned here. A neighborhood grocery store which also sells gasoline is located at the southeast corner of the intersection. There is also a service station near the southwest corner and a parking lot for a sandwich shop is on the northwest corner. All these facilities have direct access to Union Street and thus create continuous interference with traffic. However, the worst aspect is the at grade rail road crossing located 300 feet upstream on Union Street. After times of train use, serious queue of traffic on Union Street occurs at this intersection especially during afternoon peak hours.

The existing control device at the intersection is a two-phase pretimed signal with 60-second cycle length. No interconnection exists between this traffic signal and the other two traffic signals located approximately 800 feet upstream at the intersections of Union Street with 3rd Street and Union Street with 4th Street. These two intersections are only 60 feet apart from each other and the two signals are well coordinated.

The examination of Table 9 shows that the traffic volume on the north approach was less than 150 vehicles per hour in any hour of a day. On the south approach, however, the volume was greater than 150 vehicles

TABLE 9 : SUMMARY OF VEHICLE COUNTS - INTERSECTION B, OCTOBER 1978*

HOUR BEGINNING AT	UNION STREET	6TH STREET		HOUR ENDING AT
	WEST LEG	SOUTH LEG	NORTH LEG	
12AM	169	19	16	1A
1A	110	11	5	2A
2A	65	11	7	3A
3A	38	4	2	4A
4A	31	1	3	5A
5A	41	7	6	6A
6A	224	33	26	7A
7A	556	87	99	8A
8A	605	99	103	9A
9A	578	86	72	10A
10A	595	95	62	11A
11A	759	115	87	12A
12A	922	133	100	1P
1P	735	111	86	2P
2P	782	114	80	3P
3P	822	123	120	4P
4P	1234	169	127	5P
5P	1238	153	117	6P
6P	738	95	74	7P
7P	595	95	77	8P
8P	469	70	51	9P
9P	417	68	44	10P
10P	371	52	33	11P
11P	273	29	32	12P
TOTAL	12,367	1780	1429	TOTAL

* : AVERAGE DAILY TRAFFIC AS ESTIMATED FROM A THREE-DAY 24-HOUR COUNT DURING THE MONTH

per hour during the two afternoon peak hours (4:00 p.m. to 6:00 p.m.). For Union Street, the traffic volume averaged around 700 vehicles per hour in the day time with a sharp rise to nearly 1300 vehicles per hour in the afternoon peak. According to the MUTCD, this intersection did not satisfy volume warrants 1 to 3, but the traffic volume was fairly close to (although still under) the requirements of warrant 8 -- "Combination of Warrants". It should be noted, as stated in the MUTCD, that "adequate trial of other remedial measures which cause less delay and inconvenience to traffic should precede installation of signals under this warrant". The travel time-delay data provided necessary information for the following analysis.

Table 10 shows the average travel time and average delay for each turning movement of all three approaches. Rather high individual vehicle delay was found on both approaches of the minor street (6th) and each delay figure accounted for about half of its corresponding travel time. In the data collecting period, a stopping time of as long as 60 seconds was experienced on the minor north approach. The percentages of stopping were 70 and 68 respectively on the south and north approaches of 6th Street. The longest delays occurred on the north approach for through vehicles. This happened because the north approach is not marked to accommodate two approaching lanes. Thus, a through vehicle frequently had to stop behind a left-turning vehicle which was waiting to get the right-of-way from the oncoming through traffic. For a small-size car, the driver usually switched to the curb side to pass the standing left-turn vehicle and then proceeded through the intersection. This

TABLE 10: AVERAGE TRAVEL TIME AND AVERAGE DELAY BY APPROACH AND BY TURNING MOVEMENT - INTERSECTION B (TRAFFIC SIGNAL)

		PEAK HOURS			OFF-PEAK HOURS		
APPROACH	MOVEMENT	TRAP LENGTH (FEET)	AVERAGE TRAVEL TIME (SECONDS)	AVERAGE UNDELAYED TRAVEL TIME (SECONDS)	AVERAGE DELAY PER VEHICLE (SECONDS)	AVERAGE TRAVEL TIME (SECONDS)	AVERAGE UNDELAYED TRAVEL TIME (SECONDS)
UNION STREET WEST LEG	STRAIGHT	507	24.8	17.9	6.9	22.3	17.9
	R.T.	552	26.3	23.6	2.7	24.4	23.2
	L.T.	566	30.0	22.9	7.1	28.3	22.7
6TH STREET SOUTH LEG	STRAIGHT	566	38.5	19.6	18.9	34.9	17.5
	R.T.	553	37.5	20.8	16.7	31.3	20.8
6TH STREET NORTH LEG	STRAIGHT	566	46.6	18.6	28.0	44.8	16.5
	L.T.	571	42.2	23.0	19.2	40.4	21.5

4.4

1.2

5.6

17.4

10.5

28.3

18.9

was impossible for a full-size car and there was not any pavement marking that indicated two approach lanes. Under the worst condition, the through vehicle had to stop for more than one signal cycle. These long delays could be minimized by marking the approach for two lanes.

It was noted that very little delay occurred to right turn vehicles on Union Street as right turn on red was permitted. During the off-peak hours, the delay was only 1.2 seconds per vehicle.

Summarizing the above discussion, the traffic signal may not be an efficient control for this intersection. The traffic volumes exceeded warrant values during only the two afternoon peak hours and interestingly, this was the period that caused the highest delay for the minor street. STOP control at this intersection might be better.

A direct advantage of STOP control would be 1978 travel time savings on Union Street of 3200 vehicle-hours if only the 12-hour period in the day time in which data was collected was considered. For the minor street, gaps provided by the upstream traffic signal would permit traffic to cross Union Street. Field observation found adequate sight distance exists on both streets. Right turn traffic on the minor south approach as well as left turn traffic on the north approach would need only a short gap to make their turn movements into the one-way major street. At times of a train crossing at 5th Street the STOP control would undoubtedly reduce the unnecessary stopping for a red light as there would be no traffic on Union Street at all. In the long run, the expected total travel time under STOP control on the minor street might be very similar to the current signal control.

Intersection C: Union Street and 26th Street

This right angle intersection is located in the City of Lafayette. The major street (Union) serves primarily east and west bound traffic through the city. On the east leg of Union Street there is one traffic lane in each direction and a left turn pocket of 45 feet as indicated by the pavement markings. The west leg has two approach lanes with one exit lane. However, field observation indicated that the eastbound traffic on the west leg did not move as a two-lane flow until they were approximately 100 feet from the intersection. The right turn vehicles would then take the curb lane and the center lane was left for through traffic. The minor street (26th) is a two-lane two-way street which ends 250 feet north of the intersection. Because that 250-foot section of 26th Street is unpaved and carries a negligible amount of traffic, the intersection was treated as a T-intersection in this study. The average hourly volumes in October 1978 on both streets are presented in Table 11. The ADT on Union Street was 10,630 and 26th Street, 1310 -- a volume split of approximately 90-10.

The control device at the intersection often operates as a two-phase pretimed traffic signal with cycle length of 45 seconds. Right turn on red is permitted. The speed limit on Union Street is 30 miles per hour and on 26th Street, 20 miles per hour (because of a nearby school).

An examination of Table 11 indicates that the traffic volumes on the minor south approach were less than 100 vehicles per hour for most of the hours of a day and were approximately 150 vehicles per hour only during the two-hour period of 3:00 p.m. to 5:00 p.m. This made

TABLE 11 : SUMMARY OF VEHICLE COUNTS - INTERSECTION C, OCTOBER 1978*

HOUR BEGINNING AT	UNION STREET		26TH STREET	HOUR ENDING AT
	EAST LEG	WEST LEG	SOUTH LEG	
12AM	38	63	8	1A
1A	33	34	3	2A
2A	17	22	3	3A
3A	12	16	2	4A
4A	11	7	1	5A
5A	18	18	7	6A
6A	147	107	31	7A
7A	439	267	59	8A
8A	289	239	56	9A
9A	314	236	52	10A
10A	316	282	60	11A
11A	337	369	83	12A
12A	362	390	91	1P
1P	346	340	65	2P
2P	374	365	99	3P
3P	396	478	158	4P
4P	373	500	149	5P
5P	330	485	119	6P
6P	321	283	60	7P
7P	257	227	48	8P
8P	170	184	39	9P
9P	176	180	28	10P
10P	116	145	22	11P
11P	86	116	21	12P
TOTAL	5278	5353	1310	TOTAL

* : AVERAGE DAILY TRAFFIC AS ESTIMATED FROM A THREE-DAY 24-HOUR COUNT DURING THE MONTH

the signal installation under Warrant No. 1 (Minimum Vehicular Volume) impossible. Considering Warrant No. 2 (Interruption of Continuous Traffic), the specified minimum volume of 750 vehicles per hour on the major street was satisfied only for each of four hours of a day. This did not warrant the traffic signal either.

Delay data for each approach and turning movement are shown in Table 12. For the through traffic on the major street, the delay for each vehicle during peak hours was considerably higher than that during off-peak hours. For example, through traffic on the east approach of Union Street suffered a delay increase from 4.1 to 8.2 seconds, an increase of 100 percent. On the other hand, delay for the minor street (26th) traffic remained approximately unchanged during both peak and off-peak hours. The right turn lane on the west approach of Union Street associated with the permitted right turn on red operation proved to be efficient as the delay was only about one second at all times. Right turn on red also reduced the delay on 26th Street.

Considering the fact that nearly 90 percent of the major street traffic is through vehicles and the correspondingly relative high delay for them, a STOP sign on 26th Street might be a better control than the existing traffic signal. For only the 12-hour period in the day time in which data was collected, the resulting 1978 travel time savings on the major street was estimated to be 3300 vehicles-hours. Field observations also indicated that the platoon effect caused by two adjacent traffic signals (approximately one-half mile away) is not seriously disrupted and adequate gaps are provided for the minor street traffic. During peak hours, however, delay for the minor street

TABLE 12: AVERAGE TRAVEL TIME AND AVERAGE DELAY BY APPROACH AND BY TURNING MOVEMENT - INTERSECTION C (TRAFFIC SIGNAL)

		PEAK HOURS			OFF-PEAK HOURS			
APPROACH	MOVEMENT	TRAP LENGTH (FEET)	AVERAGE TRAVEL TIME (SECONDS)	AVERAGE UNDELAYED TRAVEL TIME (SECONDS)	AVERAGE DELAY PER VEHICLE (SECONDS)	AVERAGE TRAVEL TIME (SECONDS)	AVERAGE UNDELAYED TRAVEL TIME (SECONDS)	AVERAGE DELAY PER VEHICLE (SECONDS)
UNION STREET	STRAIGHT	920	30.7	22.5	8.2	25.5	21.4	4.1
	L.T.	806	41.1	27.5	13.6	37.1	26.0	11.1
UNION STREET	STRAIGHT	920	33.3	23.3	10.0	25.1	19.8	5.3
	R.T.	765	27.8	26.7	1.1	27.7	26.7	1.0
26TH STREET	R.T.	770	34.8	26.3	8.5	34.4	26.3	8.1
	L.T.	801	39.3	23.3	16.0	38.1	23.0	15.1

traffic might possibly increase under STOP sign control, but for the other hours of the day no significant increase should occur.

Intersection D: Teal Road and 30th Street

This T-intersection is located on the southeast side of the City of Lafayette. The major road (Teal) which is part of Indiana State Road 25 carries heavy traffic between U.S. 52 and U.S. 231. There are two lanes in each direction and many business facilities on the south side of the road. The minor street (30th) which is a two-lane two-way street starts approximately 1000 feet south of the intersection. A steel company as well as a few warehouses are located on both sides of 30th Street. The existing control device for the T-intersection is a STOP sign on the south approach. Field observation indicated adequate sight distance for both streets. The average hourly volumes in August 1978 on both streets are presented in Table 13. For a 12-hour period, traffic from both major street approaches accounted for 97 percent of the total entering volume.

An examination of Table 13 found no traffic signal warrant was met according to the MUTCD. In fact, the traffic volume on the south approach remained less than 50 vehicles per hour through nearly all the hours of a day. Considering the relatively high volume on the major street, a long delay for the minor street vehicle should be expected. The observed average delay for the minor street vehicle is shown in Table 14. It was noted that left turn vehicles suffered more than double delay (nearly 30 seconds) than right turn vehicles did. Also noted was the rather constant delay during both peak and

TABLE 13 : SUMMARY OF VEHICLE COUNTS - INTERSECTION D, AUGUST 1978*

HOUR BEGINNING AT	TEAL ROAD		30TH STREET	HOUR ENDING AT
	EAST LEG	WEST LEG	SOUTH LEG	
6AM	181	330	6	7A
7A	387	521	23	8A
8A	323	420	22	9A
9A	370	440	17	10A
10A	483	622	36	11A
11A	557	601	41	12A
12A	700	736	43	1P
1P	661	744	34	2P
2P	613	698	37	3P
3P	758	656	43	4P
4P	754	788	31	5P
5P	759	701	80	6P
TOTAL	6546	7257	415	TOTAL

* : AVERAGE HOURLY VOLUME AS ESTIMATED FROM A TWO-DAY 12-HOUR COUNT DURING THE MONTH

TABLE 14: AVERAGE TRAVEL TIME AND AVERAGE DELAY BY TURNING MOVEMENT FOR THE MINOR STREET - INTERSECTION D (STOP SIGN)

		PEAK HOURS			OFF-PEAK HOURS		
APPROACH	MOVEMENT	TRAP LENGTH (FEET)	AVERAGE TRAVEL TIME (SECONDS)	AVERAGE UNDELAYED TRAVEL TIME (SECONDS)	AVERAGE DELAY PER VEHICLE (SECONDS)	AVERAGE TRAVEL TIME (SECONDS)	AVERAGE UNDELAYED TRAVEL TIME (SECONDS)
30TH STREET	R.T.	718	34.4	20.5	13.9	32.1	20.5
							11.6
SOUTH LEG	L.T.	795	52.0	22.1	29.9	51.2	22.1
							29.1

off-peak hours. This was due to little fluctuation of traffic volume on the major street as indicated in Table 13.

A simulation study using NETSIM model was conducted to investigate the effect of signalization on vehicle travel times through the intersection. The traffic signal utilized in this simulation was a semi-actuated signal with background cycle length of 60 seconds. Those trap lengths used in collecting field data were input to the model to generate comparable travel times. Six replicated runs, each simulating 15 minutes of real time, were obtained to provide confidence in the simulated mean at a level of five percent. The average NETSIM travel time estimates are tabulated against observed average travel times (under STOP sign control) in Table 15.

A first glance of Table 15 indicates that when a semi-actuated traffic signal is employed, travel times change significantly except for that of right turn vehicles on the west approach. Travel times for both right turns and left turns from 30th Street reduced considerably under signal control. The left turn vehicles decreased their travel time by nearly 50 percent. Reduced travel time was also found for the left turn vehicles from the east approach. On the other hand, through traffic on the major street, by far the major volume, suffered a significantly increased travel time. The increase ranged from 42 to 53 percent.

From Table 15, it might seem that the semi-actuated signal worked out better than the STOP sign did. However, one should be aware that the travel time changes must be weighted by their corresponding traffic volumes to draw a meaningful conclusion on the relative

TABLE 15 : AVERAGE TRAVEL TIME IN SECONDS UNDER DIFFERENT INTERSECTION CONTROL DEVICES - INTERSECTION D

APPROACH	MOVEMENT	PEAK HOURS			OFF-PEAK HOURS		
		(1) TWO-WAY STOP SIGN	(2) SEMI-ACTUATED SIGNAL	DIFFERENCE	(1) TWO-WAY STOP SIGN	(2) SEMI-ACTUATED SIGNAL	DIFFERENCE
TEAL ROAD EAST LEG	STRAIGHT	16.7	24.0	+ 7.3	15.8	24.1	+ 8.3
	L.T.	35.1	22.8	- 12.3	30.0	22.9	- 7.1
TEAL ROAD WEST LEG	STRAIGHT	16.7	23.9	+ 7.2	16.6	23.7	+ 7.1
	R.T.	23.2	24.4	+ 1.2	23.0	24.5	+ 1.5
30TH STREET SOUTH LEG	R.T.	34.4	25.6	- 8.8	32.1	25.9	- 6.2
	L.T.	52.0	27.4	- 24.6	51.2	28.0	- 23.2

(1) : FIELD DATA
(2) : SIMULATION DATA

efficiency or effectiveness of the two different control devices studied. The volume data in Table 13 was expanded to average yearly volume for the same 12-hour period (6:00 a.m. to 6:00 p.m.) through multiplying by a factor of 260 (approximate week days). The 1978 increase or decrease in travel delay under the two control devices were then estimated as shown in Table 16.

Table 16 indicates that the installation of a semi-actuated traffic signal would increase the total intersection travel time by 6660 vehicle-hours per year. This strongly supports the early conclusion that no traffic signal was warranted at this intersection according to the MUTCD. The existing STOP sign control under the conditions of operation of this intersection before May 1979 was the most efficient control.

In May 1979, however, a semi-actuated traffic signal was installed at this study intersection by the Indiana State Highway Commission. The signal installation was justified despite the above analysis results. The reason behind this is due to the special condition of the intersection related to an adjacent T-intersection of Teal Road and Concord Road. The relative location of these two intersections is shown in Figure 5.

Concord Road, with one lane in each direction carried considerably higher traffic volume than the parallel 30th Street. The business facilities that are located on both sides of Concord drew continuous traffic through the intersection with Teal Road. Although a traffic signal was warranted at this intersection, the close spacing (less than 300 feet) between Sagamore Parkway and Concord would not permit

TABLE 16 : ESTIMATED 1978 TRAVEL DELAY* IN VEHICLE-HOURS FOR THE STOP SIGN
AND SEMI-ACTUATED SIGNAL CONTROLS - INTERSECTION D

		CONTROL DEVICE		
APPROACH	MOVEMENT	(1) STOP SIGN	(2) SEMI-ACTUATED SIGNAL	DIFFERENCE
TEAL ROAD	STRAIGHT	7360	11,070	+ 3710
EAST LEG	L.T.	400	300	- 100
TEAL ROAD	STRAIGHT	8190	11,700	+ 3510
WEST LEG	R.T.	720	770	+ 50
30TH STREET	R.T.	430	330	- 100
SOUTH LEG	L.T.	890	480	- 410
TOTAL		17,990	24,650	+ 6660

* : PERIOD COVERED FROM 6:00 AM TO 6:00 PM

(1): FIELD DATA

(2): SIMULATION DATA

FIGURE 5 : RELATIVE LOCATION OF INTERSECTION D

proper intersection operation under signal control. The high volumes of left turns from Teal to Concord, and from Concord to Teal, not only suffered long delays themselves but also created serious interference with through traffic on Teal. The congested condition was even worse during peak periods when the traffic backup from the intersection of Sagamore and Teal blocked Concord Road and/or Teal Road at this intersection.

The solution to this problem was to prohibit both left turns from Teal to Concord and Concord to Teal. These left turns were diverted through the intersection of Teal and 30th by way of Summer Street. Summer Street, which is a 24-foot two-lane two-way street, is parallel to and approximately 1150 feet south of Teal Road. The above operation undoubtedly increased the traffic volume on 30th Street to the warranted amount. Thus, a traffic signal installation was needed at this intersection.

Some other measures were also done to supplement the operation. NO LEFT TURN signs and a right turn channelization island were installed at the intersection of Teal and Concord. Two message signs -- TO WESTBOUND TEAL RD and NO LEFT TURN AT TEAL RD -- were installed at the intersection of Concord and Summer. An advance message of TO WESTBOUND TEAL RD -- NEXT LEFT was also provided on Concord approximately 300 feet south of Summer Street.

The resulting signal installation at Teal and 30th indicates an important point: The traffic signal installation at a particular location cannot always solely be based upon the traffic volumes at it;

due consideration must be given to the physical location and operational characteristics of the intersection with respect to the entire traffic flow network in which it exists.

Intersection E: State Street and Airport Road

This 90-degree intersection is located on the west side of Purdue University. The major street (State), which is part of Indiana State Road 26, is a two-lane two-way arterial that carries east-west traffic. A 132-foot left turn pocket is provided on the east approach of the intersection. The minor road (Airport) which is part of State Road 526 serves as a collector for the university's residential apartments and for the Purdue Airport both located south of the intersection. On the north leg of Airport Road, there are two lanes in each direction. Only one lane in each direction is provided on the south leg. The shopping center that is located at the northeast corner of the intersection as well as the numerous residence halls and apartments in this area draw continuous traffic through the intersection. Table 17 shows the average hourly volumes in October 1977 on both roads for the period 6:00 a.m. to 6:00 p.m. In this 12-hour period, traffic from the major-street approaches accounted for approximately 55 percent of the total entering volume.

The existing control device at this intersection was a four-way STOP control supplemented by a beacon with flashing red indication facing each approach. Field observation of traffic operation at this intersection indicated that the flow on both roads was generally smooth under the four-way STOP control. However, moderated delays

TABLE 17 : SUMMARY OF VEHICLE COUNTS - INTERSECTION E, OCTOBER 1977*

HOUR BEGINNING AT	STATE STREET		AIRPORT ROAD		HOUR ENDING AT
	EAST LEG	WEST LEG	SOUTH LEG	NORTH LEG	
6AM	31	92	20	20	7A
7A	104	411	93	73	8A
8A	160	324	124	130	9A
9A	167	189	131	132	10A
10A	156	145	93	113	11A
11A	224	185	138	205	12A
12A	231	198	188	214	1P
1P	218	182	143	169	2P
2P	223	163	160	181	3P
3P	261	152	194	201	4P
4P	346	184	180	289	5P
5P	475	167	241	344	6P
TOTAL	2596	2392	1705	2071	TOTAL

* : AVERAGE HOURLY VOLUME AS ESTIMATED FROM A TWO-DAY 12-HOUR COUNT DURING THE MONTH

as well as moderately long queues were also found during peak hours.

The average delay for each movement on all approaches is presented in Table 18. As expected, delays during the peak period were larger than those during the off-peak period except for that of left turns from the east approach. The 132-foot left turn pocket on the east approach not only helped to reduce the delay for left turn vehicles but also improved the condition for through and right turn vehicles. For the minor road, less delay was found on the north approach because two lanes were provided.

It is generally found that four-way STOP control works to the best advantage of traffic when the flow on the two cross streets is approximately equal. This is because a regular discharge pattern tends to develop with very little lost time. On the other hand when there is an unbalanced demand, the lighter flow receives unwarranted advantage over the heavier flow, in terms of discharge time received relative to demand. An examination of Table 17 shows that the volume of traffic on the intersecting roads remained rather constant throughout most of the day time period. The hourly volumes for the 6:00 a.m. to 6:00 p.m. period on the major road averaged 420 vehicles and on the minor road, 320 vehicles.

According to the MUTCD, a multi-way STOP control may be warranted if the volumes of traffic on all approaches are approximately equal. Although this is generally true for this intersection over the 12 hours noted in Table 17, the volumes during the peak hours do not have such a characteristic. The MUTCD also suggests that for a four-way STOP control, at least 500 vehicles must enter the intersection from

TABLE 18 : AVERAGE DELAY PER VEHICLE BY APPROACH AND BY TURNING MOVEMENT
- INTERSECTION E (FOUR-WAY STOP)

APPROACH	MOVEMENT	TRAP LENGTH (FEET)	PEAK HOURS	OFF-PEAK HOURS
			AVERAGE DELAY PER VEHICLE (SECONDS)	AVERAGE DELAY PER VEHICLE (SECONDS)
STATE STREET EAST LEG	STRAIGHT	814	15.2	12.4
	R.T.	866	16.4	10.9
	L.T.	858	13.7	13.7
STATE STREET WEST LEG	STRAIGHT	814	16.1	14.2
	R.T.	816	14.6	11.8
	L.T.	877	16.3	12.0
AIRPORT ROAD SOUTH LEG	STRAIGHT	928	17.6	11.4
	R.T.	829	14.2	12.5
	L.T.	838	18.8	14.1
AIRPORT ROAD NORTH LEG	STRAIGHT	928	12.9	9.6
	R.T.	844	11.0	10.0
	L.T.	914	14.6	12.9

all approaches for at least eight hours. This intersection meets that criterion. The second criterion required for the volume warrant is at least 200 vehicles on the minor approaches and a 30 seconds average delay during the maximum hours under two-way STOP control for those vehicles. More than 200 vehicles were present but, although not measured because two-way STOP control could not be actually installed, it is doubtful because of the moderate volumes involved that the 30 seconds delay criterion would have been met.

Although the traffic volumes in Table 17 were lower than the required amount in "Minimum Vehicular Volume" warrant, some special characteristics of this particular intersection deserved further consideration to determine the necessity for a signal installation.

First of all, this location lies at the edge of the city. The area west of the intersection is, in fact, mostly rural in nature. The major road (S.R. 26 or State Street) enters and traverses the city starting from this intersection. With a relatively near traffic signal system beginning 2500 feet away, a traffic signal installation at this intersection may very possibly serve to achieve a more concentrated and organized traffic flow network.

Second, it was noted that the west approach of the major road and the north approach of the minor road both have a posted speed limit of 40 miles per hour. These high approach speeds coupled with the rural environment west of the intersection indicates that the criteria of 70 percent of the required minimum vehicular volume for signal installation is applicable to this intersection. Using that 70 percent

criteria, the traffic volumes at this intersection satisfy the warrant for signal installation. As a consequence, a traffic signal is warranted at this location.

To further investigate the need for a traffic signal at this intersection, a simulation study was conducted to study the effect that signalization would have on intersection delay. Two different signal controllers were utilized in the simulation study. First, a two-phase pretimed signal and second, a full-actuated signal. For the pretimed controller, a short signal cycle (40 seconds) was selected which, in fact, was controlled by the pedestrian requirement rather than the minimum vehicular green time. Six replications with each simulating 15 minutes of real time were obtained for both signal controls. The average simulated travel times during peak period were tabulated against the observed average travel times (under four-way STOP control) in Table 19. Table 20 shows the results for the off-peak period.

It is no surprise to find that both signal controls reduced the average vehicular travel time. Under the pretimed signal control, however, travel time for some of the minor-road movements increased a little (all less than seven percent). The full-actuated controller proved to be efficient in responding to demands from all approaches--the travel time decreased in all cases. For the minor road, the decrease reached approximately 30 percent during the peak period.

The 1978 increase or decrease in travel delay covering the period of 6:00 a.m. to 6:00 p.m. was prepared for each of the three different

TABLE 19 : AVERAGE TRAVEL TIME IN SECONDS UNDER DIFFERENT INTERSECTION CONTROL DEVICES
- INTERSECTION E (PEAK HOURS)

APPROACH	MOVEMENT	(1) FOUR-WAY STOP SIGN		(2) PRETIMED TRAFFIC SIGNAL		(3) FULL-ACTUATED TRAFFIC SIGNAL	
		VALUE		VALUE	DIFFERENCE	VALUE	DIFFERENCE
STATE STREET EAST LEG	STRAIGHT R.T. L.T.	30.2		25.1	- 5.1	26.4	- 3.8
		35.6		28.2	- 7.4	28.6	- 7.0
		30.7		26.2	- 4.5	26.5	- 4.2
STATE STREET WEST LEG	STRAIGHT R.T. L.T.	31.2		25.0	- 6.2	23.7	- 7.5
		30.5		25.5	- 5.0	23.7	- 6.8
		34.0		27.5	- 6.5	25.7	- 8.3
AIRPORT ROAD SOUTH LEG	STRAIGHT R.T. L.T.	37.5		34.4	- 3.1	25.4	- 12.1
		31.3		31.9	+ 0.6	23.4	- 7.9
		34.5		31.3	- 3.2	23.2	- 11.3
AIRPORT ROAD NORTH LEG	STRAIGHT R.T. L.T.	33.3		31.5	- 1.8	25.4	- 7.9
		29.3		30.4	+ 1.1	25.3	- 4.0
		34.3		31.0	- 3.3	25.5	- 8.8

(1) : FIELD DATA
(2) AND (3) : SIMULATION DATA

TABLE 20 : AVERAGE TRAVEL TIME IN SECONDS UNDER DIFFERENT INTERSECTION CONTROL DEVICES
- INTERSECTION E (OFF-PEAK HOURS)

APPROACH	MOVEMENT	(1) FOUR-WAY STOP SIGN		(2) PRETIMED TRAFFIC SIGNAL		(3) FULL-ACTUATED TRAFFIC SIGNAL	
		VALUE		VALUE	DIFFERENCE	VALUE	DIFFERENCE
STATE STREET EAST LEG	STRAIGHT R.T. L.T.	28.4		24.8	- 3.6	24.1	- 4.3
		30.1		27.8	- 2.3	26.5	- 3.6
		30.7		26.4	- 4.3	24.7	- 6.0
STATE STREET WEST LEG	STRAIGHT R.T. L.T.	29.3		25.3	- 3.0	23.5	- 5.8
		27.7		27.1	- 0.6	23.7	- 4.0
		29.7		28.5	- 1.2	25.5	- 4.2
AIRPORT ROAD SOUTH LEG	STRAIGHT R.T. L.T.	31.3		30.0	- 1.3	26.0	- 5.3
		29.6		27.8	- 1.8	24.0	- 5.6
		29.8		26.9	- 2.9	23.6	- 6.2
AIRPORT ROAD NORTH LEG	STRAIGHT R.T. L.T.	30.0		31.8	+ 1.8	25.7	- 4.3
		28.3		30.2	+ 1.9	25.1	- 3.2
		32.6		31.0	- 1.6	25.5	- 7.1

(1) : FIELD DATA

(2) AND (3) : SIMULATION DATA

intersection controls. A comparison of them is shown in Table 21. The pretimed signal reduced the yearly total intersection travel delay from 19,350 to 17,760 vehicle-hours -- a decrease of eight percent (1590 vehicle-hours). For the full-actuated signal, the travel delay decrease was more than doubled (18 percent or 3540 vehicle-hours).

Table 21 coincides with and strongly supports the previous analysis results that the traffic volumes at this intersection warrant a traffic signal installation. The existing four-way STOP control was thus not the best efficient control and perhaps should be replaced by a traffic signal. As of June 1979, a traffic signal installation was in progress at this intersection.

Intersection F: Indiana State Road 26 and Creasy Lane

The right angle intersection is located on the east side of the City of Lafayette and just at the city limit. The major road (S.R. 26) is a four-lane two-way road divided by a concrete barrier along the center line. Left turn as well as right turn pockets are provided on both approaches of the road. S.R. 26 carries east and west bound traffic as a major arterial and an interchange with Interstate 65 is located approximately 4700 feet east of the intersection. The minor road (Creasy Lane), which is Tippecanoe County Road 350, serves as a collector for a built-up residential and commercial area north of the intersection. There is one lane in each direction on Creasy Lane and a right turn pocket of 235 feet is provided on the south approach. The speed limit on S.R. 26 is 50 miles per hour and on Creasy Lane, 30 miles per hour for the north leg and 40 miles per hour for the south

TABLE 21: ESTIMATED 1978 TRAVEL DELAY* IN VEHICLE-HOURS FOR THREE DIFFERENT INTERSECTION CONTROLS - INTERSECTION E

APPROACH	MOVEMENT	(1) FOUR-WAY STOP SIGN		(2) PRETIMED TRAFFIC SIGNAL		(3) FULL-ACTUATED TRAFFIC SIGNAL	
		VALUE		VALUE	DIFFERENCE	VALUE	DIFFERENCE
STATE STREET EAST LEG	STRAIGHT	2390		2480	- 410	2480	- 410
	R.T.	1250		1100	- 150	1070	- 180
	L.T.	1490		1280	- 210	1220	- 270
STATE STREET WEST LEG	STRAIGHT	3340		2910	- 430	2640	- 700
	R.T.	330		300	- 30	270	- 60
	L.T.	1540		1380	- 160	1260	- 280
AIRPORT ROAD SOUTH LEG	STRAIGHT	2000		1890	- 110	1570	- 430
	R.T.	1500		1430	- 70	1190	- 310
	L.T.	390		350	- 40	300	- 90
AIRPORT ROAD NORTH LEG	STRAIGHT	1750		1790	+ 40	1440	- 310
	R.T.	1390		1460	+ 70	1220	- 170
	L.T.	1480		1390	- 90	1150	- 330
TOTAL		19,350		17,760	- 1590	15,810	- 3540

* : PERIOD COVERED FROM 6:00 AM TO 6:00 PM

(1) : FIELD DATA

(2) AND (3) : SIMULATION DATA

leg. The average hourly volumes in October 1977 on both streets are presented in Table 22. For this 12-hour period, traffic from both major road approaches accounted for 85 percent of the total entering volume. Two-way STOP signs are installed on both approaches of Creasy Lane to control the minor traffic.

An examination of Table 22 indicates that the volume of intersecting traffic satisfied the warrants for signal installation. It should be noted here that since the 85-percentile speed on S.R. 26 exceeded 40 miles per hour, the minimum volume warrant and the interruption of continuous traffic warrant are only 70 percent of the requirements of Warrant 1 and 2 of the MUTCD. Table 22 also indicates the fluctuation in traffic for both streets.

The average delays for the STOP controlled minor road traffic are shown in Table 23. Considerable long delay was present for all of its turning movements, especially during peak hours. Such delay accounted for a large percentage of the corresponding travel times. This percentage ranged from 45 for the off-peak hours to nearly 70 for the peak hours. Because the traffic volume from the north approach was much higher than that from the south approach, the average delay on the north approach was considerably longer as reflected in the Table. Also noted was the significant increase in delay during peak hours on the north approach. For a through vehicle, the delay increased from 22.5 to 60.2 seconds -- a nearly threefold increase.

Field trips were further made to observe the traffic condition at the study location. It was found that some motorists from the minor road tended to accept an inadequate gap in order to shorten the

TABLE 22 : SUMMARY OF VEHICLE COUNTS - INTERSECTION F, OCTOBER 1977*

HOUR BEGINNING AT	S.R. 26		CREASY LANE		HOUR ENDING AT
	EAST LEG	WEST LEG	NORTH LEG	SOUTH LEG	
6AM	440	91	52	12	7A
7A	552	213	173	25	8A
8A	428	259	150	21	9A
9A	323	284	90	16	10A
10A	286	252	26	13	11A
11A	358	360	61	12	12A
12A	396	408	112	16	1P
1P	414	442	120	25	2P
2P	451	449	107	24	3P
3P	377	642	129	16	4P
4P	401	720	137	31	5P
5P	351	854	168	14	6P
TOTAL	4839	4974	1391	225	TOTAL

* : AVERAGE HOURLY VOLUME AS ESTIMATED FROM A TWO-DAY 12-HOUR COUNT DURING THE MONTH

TABLE 23: AVERAGE TRAVEL TIME AND AVERAGE DELAY BY TURNING MOVEMENT FOR THE MINOR STREET - INTERSECTION F (STOP SIGN)

		PEAK HOURS			OFF-PEAK HOURS		
APPROACH	MOVEMENT	TRAP LENGTH (FEET)	AVERAGE TRAVEL TIME (SECONDS)	AVERAGE UNDELAYED TRAVEL TIME (SECONDS)	AVERAGE DELAY PER VEHICLE (SECONDS)	AVERAGE UNDELAYED TRAVEL TIME (SECONDS)	AVERAGE DELAY PER VEHICLE (SECONDS)
CREASY LANE SOUTH LEG	STRAIGHT	1402	61.9	28.9	33.0	54.1	28.9
	R.T.	1327	40.6	21.9	18.7	36.6	21.9
	L.T.	1514	69.5	23.7	45.8	64.5	23.7
CREASY LANE NORTH LEG	STRAIGHT	1402	88.2	28.0	60.2	50.5	28.0
	R.T.	1459	60.3	27.6	32.7	46.4	27.6
	L.T.	1399	71.7	25.8	45.9	48.8	25.8

the delay. This was especially true for through and left turn traffic. In addition, the high approach speed as well as the relatively high volume on the major road made the crossing even more hazardous. For example, left turn vehicles from the minor road approaches sometimes entered the intersection by stopping at the inadequate median (only seven feet wide), thus not only blocking the left turn lanes on the major road but also forcing the through vehicles on the major road to switch from the left lane to the right lane. Other traffic conflicts were also observed including "turn into wrong lane", "opposing left turn", and "weave on major road". These conflicts all indicated a high potential accident situation for this intersection. On the north approach of the minor road, considerable traffic queuing occurred during both a.m. and p.m. peaks. A waiting time to enter S.R. 26 of as high as 3 minutes was experienced in the data collection period. Another traffic characteristic noted was the high percentage (17 percent of the total entering volume) of commercial vehicles on both roads. The different operating characteristics of these vehicles obviously made the traffic condition more complex.

Since the traffic volume warranted the installation of a traffic signal, a suitable signal controller was selected and then the traffic was simulated under its control by the NETSIM model. In view of the fluctuation in traffic for both roads and the isolated condition of the intersection, a full-actuated traffic signal was considered to provide the most efficient control. Furthermore, variable initial and gap reduction features were added to the controller to facilitate the high speed traffic on the major road. The signal operated in three phases with an exclusive phase for left-turning traffic on the major

road. An all-red clearance interval of two-second length was used to clear the intersection before switching the right-of-way. Twelve replicated runs with each simulating ten minutes of real time were made. The resulting average travel time estimates by the NETSIM model were tabulated against the observed average travel times (under the existing STOP control) in Table 24.

As expected, Table 24 indicates that travel time for the minor traffic reduced considerably under full-actuated signal control. The decrease in travel time averaged about 40 percent during peak hours and 20 percent during the off-peak hours. On the other hand, through traffic on the major road suffered an increase in travel time of six to seven seconds. Table 24 was combined with the 12-hour entering volume to estimate the 1978 increase or decrease in travel delay for the intersection under both STOP and signal controls. The results are presented in Table 25.

It is interesting to find that even with full-actuated signal control a 1978 travel time net increase of 1130 vehicle-hours occurred. The reason is that the travel time saved by the minor traffic was not large enough to offset the increase in major-road travel time. However, it was also noted that this increase was less than five percent of the total travel time through the trapped areas. The efficiency of the signal was reduced by the use of an exclusive left-turn phase. This can be seen from the Table as the savings for left-turn traffic on the major road was not very great. Nevertheless, this separate left-turn phase was considered desirable because of the

TABLE 24 : AVERAGE TRAVEL TIME IN SECONDS UNDER DIFFERENT INTERSECTION CONTROL DEVICES - INTERSECTION F

APPROACH	MOVEMENT	PEAK HOURS			OFF-PEAK HOURS		
		(1) TWO-WAY STOP SIGN	(2) FULL-ACTUATED SIGNAL	DIFFERENCE	(1) TWO-WAY STOP SIGN	(2) FULL-ACTUATED SIGNAL	DIFFERENCE
S.R. 26 EAST LEG	STRAIGHT	22.0	28.4	+ 6.4	21.0	28.1	+ 7.1
	R.T.	33.6	33.8	+ 0.2	33.0	33.1	+ 0.1
	L.T.	43.1	30.6	- 12.5	40.3	30.5	- 9.8
S.R. 26 WEST LEG	STRAIGHT	21.3	28.0	+ 6.7	20.7	27.6	+ 6.9
	R.T.	31.8	33.1	+ 1.3	31.3	33.0	+ 1.7
	L.T.	42.2	36.3	- 5.9	41.7	35.6	- 6.1
CREASY LANE SOUTH LEG	STRAIGHT	61.9	41.9	- 20.0	54.1	43.7	- 10.4
	R.T.	40.6	34.0	- 6.6	36.6	35.8	- 0.8
	L.T.	69.5	36.6	- 32.9	64.5	38.8	- 25.7
CREASY LANE NORTH LEG	STRAIGHT	58.2	46.5	- 11.7	50.5	40.7	- 9.8
	R.T.	60.3	44.4	- 15.9	46.4	38.4	- 8.0
	L.T.	71.7	41.4	- 30.3	48.8	35.3	- 13.5

(1) : FIELD DATA

(2) : SIMULATION DATA

TABLE 25 : ESTIMATED 1978 TRAVEL DELAY* IN VEHICLE-HOURS FOR THE STOP SIGN
AND FULL-ACTUATED SIGNAL CONTROLS - INTERSECTION F

		CONTROL DEVICE		
APPROACH	MOVEMENT	(1) STOP SIGN	(2) FULL-ACTUATED SIGNAL	DIFFERENCE
S.R. 26 EAST LEG	STRAIGHT	6340	8170	+ 1830
	R.T.	1760	1770	+ 10
	L.T.	300	210	- 90
S.R. 26 WEST LEG	STRAIGHT	6080	8030	+ 1950
	R.T.	340	360	+ 20
	L.T.	2410	2060	- 350
CREASY LANE SOUTH LEG	STRAIGHT	680	460	- 220
	R.T.	3550	2810	- 740
	L.T.	3020	2000	- 1020
CREASY LANE NORTH LEG	STRAIGHT	360	260	- 100
	R.T.	230	200	- 30
	L.T.	290	160	- 130
TOTAL		25,360	26,490	+ 1130

* : PERIOD COVERED FROM 6:00 AM TO 6:00 PM
(1): FIELD DATA
(2): SIMULATION DATA

following: First, left turns constituted nearly ten percent of the total movement from the major road; second, the accident potential with the high speed opposing traffic was considerable; and third, adequate exclusive left turn lanes were available.

This intersection study did reveal one important point: traffic signals are not the solution to all traffic and accident problems. Even if a signal is warranted, as it was in this case, it may result in increased total intersection delay. Many previous studies on intersection delay have found the same results (47,48,49). Thus, warrants in conjunction with professional judgement based on experience and consideration of all related factors must be used in arriving at a decision on signal installation. Equally important is the need for proper maintenance standards and for frequent checking of the efficiency of the traffic signal timing and operation after installation.

Intersection G: Wiggins Street and Salisbury Street

and

Intersection H: Fowler Avenue and Salisbury Street

These two intersections were analyzed together because they are only 216 feet apart. The physical layout of the two intersections are shown in Figure 6. The two major streets (Wiggins and Fowler) are both one-way streets with two moving lanes and parking on both sides of each street. They serve as part of U.S. 231. The minor street (Salisbury) is a two-lane two-way street which carries north-south traffic through the City of West Lafayette. Appropriate left- or

FIGURE 6. PHYSICAL LAYOUT OF INTERSECTION G AND H

right-turn channelization is provided on the approaches of Salisbury Street at both intersections. The average hourly volumes in April 1978 on the intersecting streets are presented in Table 26 and 27 respectively for intersection G and H.

The traffic on the minor street (Salisbury) is controlled by STOP signs at both intersections. At intersection G, sight distance is restricted for the minor-street approaches because of parked vehicles on both sides of Wiggins Street. On the south approach of intersection H, the sight distance is also limited due to the curved east leg. The motorist has to pull out his vehicle onto Fowler Avenue in order to see the crossing traffic on it. This creates high potential conflicts with the traffic on the major street, especially with left-turn vehicles from Fowler.

The MUTCD contains no warrants for traffic signal at intersections of one-way streets. These two intersections, as previously noted are very close together, and operate relative to traffic movements as a single intersection. If the single approach traffic volume on Wiggins is considered with the single approach traffic volume on Fowler, at least eight hours of the twelve counted have a combined total of greater than 800 vehicles per hour. This exceeds the minimum volume warrant required for a major street, both approaches, by 200 vehicles per hour. The volume warrant on the minor street major approach is in excess of the warranted amount. As a consequence, it could be considered that the volumes at these intersections may warrant traffic signals. The limiting sight distance from the minor streets also serve to encourage signal installation.

TABLE 26 : SUMMARY OF VEHICLE COUNTS - INTERSECTION G, APRIL 1978*

HOUR BEGINNING AT	WIGGINS STREET	SALISBURY STREET		HOUR ENDING AT
	WEST LEG	SOUTH LEG	NORTH LEG	
6AM	88	29	26	7A
7A	248	102	211	8A
8A	247	78	262	9A
9A	232	92	175	10A
10A	222	98	135	11A
11A	300	163	165	12A
12A	341	134	169	1P
1P	320	118	215	2P
2P	394	144	194	3P
3P	426	192	219	4P
4P	542	202	193	5P
5P	250	248	261	6P
TOTAL	4110	1600	2225	TOTAL

* : AVERAGE HOURLY VOLUME AS ESTIMATED FROM A TWO-DAY, 12-HOUR COUNT DURING THE MONTH

TABLE 27 : SUMMARY OF VEHICLE COUNTS - INTERSECTION H, APRIL 1978*

HOUR BEGINNING AT	FOWLER AVENUE	SALISBURY STREET		HOUR ENDING AT
	EAST LEG	SOUTH LEG	NORTH LEG	
6AM	150	24	45	7A
7A	714	30	92	8A
8A	676	42	182	9A
9A	461	63	151	10A
10A	391	68	128	11A
11A	476	111	151	12A
12A	505	108	151	1P
1P	513	75	148	2P
2P	438	77	105	3P
3P	573	122	188	4P
4P	624	93	163	5P
5P	636	124	150	6P
TOTAL	6157	942	1654	TOTAL

* : AVERAGE HOURLY VOLUME AS ESTIMATED FROM A TWO-DAY 12-HOUR COUNT DURING THE MONTH

Difficulty was encountered in setting up the trap for the travel time test-car runs. The two intersections are so close to each other that it is impossible to place a trap on the 216-foot section of Salisbury Street. However, since the two major streets are both one-way streets but with different direction and the 216-foot section practically serves as a storage area, it is reasonable to combine the two intersections into one. The traps thus used in collecting field data are shown in Figure 6. In this context, a through movement from the south approach meant the vehicle crossed two major streets to reach the north end of the trap, whereas a left turn movement from the same approach meant the vehicle crossed Wiggins Street and then turned left into Fowler Avenue. For each of the major streets, the trap for left turn movement extended to the far north or south end (crossing the other major street).

The average travel times and average delays that were gathered by floating-car method are presented in Table 28. Considerably long delay was present on Salisbury Street, especially for through and left-turn vehicles. These vehicles had to stop twice to make their desired movements. Considering only the 12-hour period of 6:00 a.m. to 6:00 p.m., the delay on the minor street added up to as much as 5200 vehicle-hours in 1978. As a result, the traffic flow on Salisbury Street was seriously delayed by both intersections with STOP control on Salisbury.

TABLE 28: AVERAGE TRAVEL TIME AND AVERAGE DELAY BY APPROACH AND BY TURNING MOVEMENT - INTERSECTION G AND H (STOP SIGN)

APPROACH	MOVEMENT	TRAP LENGTH (FEET)	PEAK HOURS			OFF-PEAK HOURS		
			AVERAGE TRAVEL TIME (SECONDS)	AVERAGE UNDELAYED TRAVEL TIME (SECONDS)	AVERAGE DELAY PER VEHICLE (SECONDS)	AVERAGE TRAVEL TIME (SECONDS)	AVERAGE UNDELAYED TRAVEL TIME (SECONDS)	AVERAGE DELAY PER VEHICLE (SECONDS)
FOWLER AVE EAST LEG	STRAIGHT	761	17.7	17.7	0.0	17.1	17.1	0.0
	R.T.	864	27.1	27.1	0.0	26.9	26.9	0.0
	L.T.	978	44.0	30.4	13.6	40.1	30.4	9.7
WIGGINS ST WEST LEG	STRAIGHT	657	14.4	14.4	0.0	14.0	14.0	0.0
	R.T.	620	20.8	20.8	0.0	20.6	20.6	0.0
	L.T.	1096	47.7	35.4	11.3	45.9	35.4	9.5
SALISBURY ST SOUTH LEG	STRAIGHT	1077	65.4	29.3	36.1	51.7	29.3	22.4
	R.T.	623	29.1	17.0	12.1	25.4	17.0	8.4
	L.T.	919	55.7	25.0	30.7	55.5	25.0	30.5
SALISBURY ST NORTH LEG	STRAIGHT	1077	63.7	29.3	34.4	55.3	29.3	26.0
	R.T.	805	35.9	21.9	14.0	33.5	21.9	11.6
	L.T.	1099	63.1	29.9	33.2	51.5	29.9	21.6

Intersection I: Grant Street and North Street

This offset intersection is located in the City of West Lafayette. The physical layout of the intersection is shown in Figure 7. Grant Street, which is the major street, has two lanes in each direction and carries heavy north-south traffic. The east approach of the intersection is North Street, which has two approach lanes. With an offset of 39 feet, the west approach (Oval Drive) serves exclusively the traffic in and out of a Purdue University parking lot. The October 1978 average hourly volumes of all the approaches are tabulated in Table 29. The ADT on the major street was 10,536 and on the minor street, 3262 -- a volume split of approximately 80-20.

The control devices at this intersection used to consist of a two-phase pretimed traffic signal and WALK-WAIT pedestrian signals. In the summer of 1978, Purdue University authorities changed the Oval Drive (which used to be a campus street) into a driveway for the parking lot. Since then, the traffic signal has been operated only as a flashing device at all times. The major street (Grant) has the flashing yellow indication and the minor streets (North and Oval) are faced with the flashing red indication. The pedestrian signals were also turned off when the signal was placed on flashing operation.

An examination of Table 29 indicates that the traffic volumes on the intersecting streets do not satisfy the "Minimum Vehicular Volume" warrant in MUTCD. As there are two approach lanes on both minor-street approaches, a minimum volume of 200 vehicles per hour for eight hours is required.

FIGURE 7 : PHYSICAL LAYOUT OF INTERSECTION I

TABLE 29 : SUMMARY OF VEHICLE COUNTS - INTERSECTION I, OCTOBER 1978*

HOUR BEGINNING AT	GRANT STREET		NORTH STREET		OVAL DRIVE		HOUR ENDING AT
	SOUTH LEG	NORTH LEG	EAST LEG	WEST LEG			
12AM	92	82	28	12			1A
1A	49	54	16	8			2A
2A	20	32	8	4			3A
3A	10	14	4	3			4A
4A	6	5	3	3			5A
5A	7	22	8	4			6A
6A	22	92	15	7			7A
7A	119	520	107	28			8A
8A	185	421	121	32			9A
9A	186	284	131	29			10A
10A	202	293	140	28			11A
11A	301	370	175	27			12A
12A	313	537	182	55			1P
1P	204	331	180	45			2P
2P	252	354	167	34			3P
3P	317	340	190	45			4P
4P	435	346	159	52			5P
5P	516	367	221	56			6P
6P	287	425	150	79			7P
7P	233	271	105	80			8P
8P	170	241	114	45			9P
9P	230	276	130	27			10P
10P	125	225	68	27			11P
11P	154	139	55	15			12P
TOTAL	4495	6041	2517	745			TOTAL

* : AVERAGE DAILY VOLUME AS ESTIMATED FROM A THREE-DAY 24-HOUR COUNT DURING THE MONTH

Field trips were made to observe the traffic flow under the existing flashing control. It was found that a few through vehicles on the minor street (moving from North Street to Oval Drive or vice versa) created serious interference and conflict conditions with the major-street traffic. A vehicle from North Street, for example, had to find a gap to turn right into Grant Street and then, usually, had to stand in the street waiting for another gap to make a left turn into Oval Drive. This process was long and hazardous. First, the slow right-turn maneuver (slow because the vehicle had to stop immediately after the turn) caused the through traffic on Grant Street to decelerate (even brake) or switch lanes. Second, this right-turn maneuver actually turned into the left lane (the WRONG lane, but the RIGHT lane for his next left-turn maneuver). Third, before a right turn vehicle would straighten out on Grant Street, the driver was supposed to use his left-turn signal -- this of course could not be done. Fourth, the 39-foot offset could barely accommodate two standing left-turn vehicles; a third vehicle would block the approach of North Street (or Oval Drive, if the opposite direction). These problems, of course are due to the jog design of this intersection, a geometric condition well known for similar operation problems anywhere they are located. Fortunately only a few vehicles per hour make the difficult maneuver -- Oval Drive to North or the reverse.

Following the termination of use of the traffic signal, some claimed the most imperious need for the traffic signal came from the pedestrians. The west side of the Grant Street is the university campus. A parking garage is located at the southeast corner of the

intersection and number of residence units are located on the east side of Grant Street. Pedestrian counts showed that during the period of 8:00 a.m. to 6:00 p.m., the pedestrian volume crossing Grant Street in or near the intersection averaged 302 pedestrians per hour. It was also found that approximately 60 percent of them crossed Grant Street on the north leg. Whereas for the minor street, pedestrian crossings were fewer but still averaged 80 pedestrians per hour. The total pedestrian volume on all legs added up to 462 pedestrians per hour. During the luncheon period (12:00 a.m. to 1:00 p.m.), the pedestrian volume reached its maximum--nearly 600 pedestrians per hour. This high pedestrian volume undoubtedly deserves an adequate crossing time.

It was further found that the pavement markings outlining established crosswalks had been worn away. Moreover, field observations showed that pedestrians cross Grant Street practically at any place or time. Substantial conflict between vehicle and pedestrian movements was observed throughout the data collection period. For example, in one 15-minute period (8:15 a.m. to 8:30 a.m.), as many as 29 conflicts were present. Here, a conflict was defined as an evasive action by pedestrian, such as getting caught on the middle of the street, changing of the desired crossing direction, and a running-crossing, etc.

In order to investigate the effect that signalization would have on the intersection, travel time data was collected under both the regular signal control and the flashing control. The results are presented in Table 30. For the major street, travel time increased

TABLE 30 : AVERAGE TRAVEL TIME IN SECONDS UNDER DIFFERENT INTERSECTION CONTROL DEVICES - INTERSECTION I

APPROACH	MOVEMENT	TRAP LENGTH (FEET)	PEAK HOURS			OFF-PEAK HOURS		
			FLASHING TWO-WAY STOP	FIX-TIMED TRAFFIC SIGNAL	DIFFERENCE	FLASHING TWO-WAY STOP	FIX-TIMED TRAFFIC SIGNAL	DIFFERENCE
GRANT STREET SOUTH LEG	STRAIGHT	816	20.6	31.8	+ 11.2	20.0	24.9	+ 4.9
	R.T.	673	25.3	33.8	+ 8.5	24.5	29.5	+ 5.0
	L.T.	594	26.0	45.8	+ 19.8	25.7	29.7	+ 4.0
GRANT STREET NORTH LEG	STRAIGHT	816	20.8	32.2	+ 16.4	19.7	30.4	+ 10.7
	R.T.	453	17.9	29.1	+ 10.2	17.7	25.4	+ 7.7
	L.T.	747	28.7	39.7	+ 11.0	26.8	37.7	+ 10.9
NORTH STREET EAST LEG	STRAIGHT	458	39.8	42.8	+ 8.0	31.3	45.3	+ 15.0
	R.T.	709	34.3	50.5	+ 16.2	29.7	40.4	+ 10.7
	L.T.	685	37.5	48.2	+ 10.7	29.0	45.5	+ 16.5
DUAL DRIVE WEST LEG	STRAIGHT	488	35.4	40.2	+ 4.8	32.0	35.6	+ 3.6
	R.T.	557	32.4	43.1	+ 10.7	25.8	35.2	+ 10.4
	L.T.	488	37.3	44.2	+ 6.9	27.6	39.8	+ 12.2

by nearly 60 percent during the peak hours and 35 percent during the off-peak hours under traffic signal control. Especially noted was the north leg of the major street (which carried the heaviest traffic), the through traffic suffered a travel time increase of 79 percent in peak hours and 55 percent in off-peak hours. For the minor street, the situation was also worse -- a travel time increase of 30 percent in the peak hours and 40 percent in the off-peak hours. The 1978 travel delay estimate covering the period of 6:00 a.m. to 6:00 p.m. was prepared for both intersection controls. The results are shown in Table 31.

Table 31 indicates that under traffic signal control, the yearly travel delay for the intersection increased from 22,700 to 33,040 vehicle-hours. Among the wasted 10,340 vehicle-hours was the approximately 50 percent of them from the through traffic on the north leg of Grant Street. Here, once again, we see a detrimental effect of an unwarranted traffic signal -- a large increase in total intersection travel delay.

One reason for the travel time increase at this intersection was due to the poor coordination of the study signals with the adjacent signals within the network system. The nearest two signals are only 600 feet away, from the north and the south approaches of Grant Street. A good coordination is absolutely required to reduce unnecessary delays of traffic and to improve the efficiency of any traffic signal installed at this intersection.

Another factor which contributed to the travel time increase was the bus operation. In present practice, buses load and unload

TABLE 31 : ESTIMATED 1978 TRAVEL DELAY* IN VEHICLE-HOURS FOR THE TWO-WAY
STOP AND TRAFFIC SIGNAL CONTROLS - INTERSECTION I

APPROACH	MOVEMENT	CONTROL DEVICE		DIFFERENCE
		FLASHING TWO-WAY STOP	FIX-TIMED TRAFFIC SIGNAL	
GRANT STREET SOUTH LEG	STRAIGHT	5850	7780	+ 1930
	R.T.	320	470	+ 90
	L.T.	500	670	+ 170
GRANT STREET NORTH LEG	STRAIGHT	7830	12,620	+ 4790
	R.T.	590	870	+ 280
	L.T.	320	450	+ 130
NORTH STREET EAST LEG	STRAIGHT	440	620	+ 180
	R.T.	2790	3830	+ 1090
	L.T.	2440	3610	+ 1170
OVAL DRIVE WEST LEG	STRAIGHT	290	320	+ 30
	R.T.	750	1040	+ 290
	L.T.	520	710	+ 190
TOTAL		22,700	33,040	+ 10,340

* : PERIOD COVERED FROM 6:00 AM TO 6:00 PM

passengers at two near-side bus stops located on the north and south approaches of Grant Street respectively. Since there are no parking lanes or any bay-type bus stops available, the bus actually stops on the right moving lane. This undoubtedly affects other moving traffic and increases the intersection travel time. Another disadvantage is that buses often obscure the traffic signal and pedestrians crossing in front of the bus.

Far-side bus stops, on the other hand, would have many advantages. The major ones are stated as follows:

- 1) Buses in the bus stop will not obscure the traffic signal or pedestrian movements at the intersection.
- 2) Buses can enter the traffic stream with less interference.
- 3) Waiting passengers assemble at less-crowded section of the sidewalk.

Intersection J: Salisbury Street and Stadium Avenue

This simple 90-degree intersection is located in the City of West Lafayette. The major street (Salisbury) which serves primarily north-south traffic is a two-lane two-way street with parking on both sides. The minor street (Stadium) also has one lane in each direction and parking on both sides. Both streets are part of the arterial street system of West Lafayette. The October 1978 average hourly volumes on both streets are presented in Table 32. The ADT on Salisbury Street was 4649 and on Stadium Avenue, 3011 -- a volume split of 60-40.

The existing control device at this intersection is a two-way STOP control on the minor street. A flashing beacon is also installed with flashing red indications facing the minor street and flashing yellow indications facing the major street. Two lenses

TABLE 32 : SUMMARY OF VEHICLE COUNTS - INTERSECTION J, OCTOBER 1978*

HOUR BEGINNING AT	SALISBURY STREET		STADIUM AVENUE		HOUR ENDING AT
	SOUTH LEG	NORTH LEG	EAST LEG	WEST LEG	
12AM	25	22	15	30	1A
1A	13	15	8	17	2A
2A	7	12	5	10	3A
3A	3	3	1	3	4A
4A	3	2	0	2	5A
5A	10	5	2	4	6A
6A	45	35	10	11	7A
7A	113	114	77	39	8A
8A	119	182	89	55	9A
9A	102	119	62	64	10A
10A	136	107	55	68	11A
11A	180	120	67	112	12A
12A	164	122	90	149	1P
1P	153	135	86	110	2P
2P	158	133	72	101	3P
3P	209	138	61	135	4P
4P	257	145	72	205	5P
5P	268	142	92	226	6P
6P	168	133	82	113	7P
7P	134	119	71	81	8P
8P	104	71	52	65	9P
9P	101	66	54	100	10P
10P	91	58	34	91	11P
11P	52	36	24	39	12P
TOTAL	2615	2034	1181	1830	TOTAL

* : AVERAGE DAILY VOLUME AS ESTIMATED FROM A THREE-DAY 24-HOUR COUNT DURING THE MONTH

aligned horizontally are used on each approach.

A private citizen organization formed within the neighborhood intersection area had frequently criticized this two-way STOP intersection control as failure to provide for safe traffic operation. The demands resulted in approval of a semi-actuated signal installation by the City Council. The signal, however, was not warranted by the MUTCD and Indiana regulations and has not been installed (June 1979). A travel time-delay study was included in this research to provide information on the effect that signalization would have on this intersection.

An examination of Table 32 indicates that no traffic signal warrant was met according to the MUTCD. In fact, this intersection does not warrant a four-way STOP control either. On the major street, there were only 410 vehicles during the peak hour and an average of 300 vehicles during day time. On the minor street, traffic volume remained less than 200 vehicles per hour except during the afternoon peak period (4:00 p.m. to 6:00 p.m.). The total entering volume of the intersection was lower than 500 vehicles per hour through most of the hours of a day.

The travel times and delays for the stop-controlled minor-street traffic are presented in Table 33. Delay remained somewhat similar during both peak and off-peak periods. One exception was on the west approach, the through traffic suffered a delay increase from 9.2 to 15.6 seconds. This was due to the relatively heavy eastbound traffic from Purdue University in the afternoon peak hour. On both approaches,

the delay averaged only 14.0 seconds during the peak hour and 10.7 seconds during the off-peak hours. These delay figures were far less than the 30 seconds requirement for a four-way STOP sign installation as stated in the MUTCD. Field observations also indicated that minor street traffic was not delayed beyond a normal stop during off-peak hours, while only short queues existed during the peak hour with little extra delay.

To evaluate what decrease or increase in delay would result if a traffic signal were installed at this intersection, a simulation of the intersection using the NETSIM model was made. Unfortunately the volumes of traffic at this intersection are so light on all approaches that the model was not applicable. The NETSIM model was developed and calibrated for traffic volumes found in downtown traffic and does not operate effectively where volume on all approaches are low. As a consequence, the delays found from simulation should not be compared with delays found by field measurement at this intersection. Delays, however, found from the model under different controls may be comparable and were calculated for this intersection.

The NETSIM model was utilized to simulate the intersecting traffic at this intersection under semi-actuated traffic signal control and under two-way STOP control. The background cycle length used was 35 seconds. Calls for green on the minor street were furnished by two 30-foot presence detectors installed on each of the two approaches. Right turn on red was permitted on both streets under the signal control. Six replications with each simulating 30 minutes of real time were obtained by the model for each control condition. The

average simulated travel time estimates are tabulated in Table 34.

Travel time estimates under semi-actuated traffic signal control were as expected -- they decreased on the minor street and increased on the major street. The through traffic from minor-street approaches had an average decrease of only 3.5 seconds during the peak periods and 2.9 seconds during the off-peak periods. The travel time decrease for right and left turns from the minor street was even smaller -- an average 0.8 second. On the major street, through traffic suffered an average travel time increase of 4.0 seconds (approximately 25 percent). An average travel time increase of 1.6 seconds was also present for turning traffic on the major street.

Table 34 was again combined with traffic volume data to obtain the 1978 increase or decrease in travel delays for the two different controls. The results are shown in Table 35. It was found from Table 35 that under semi-actuated traffic signal control, a cumulative travel delay of 510 vehicle-hours would have been wasted in 1978 with signal control. This travel delay increase under signal control is not large (6.5 percent), but it does indicate that total travel time will increase if the intersection is signalized. If one further considers the relative costs of equipment and maintenance, the existing control device undoubtedly proves to be better than the semi-actuated controller, as it offers a better level of service with less cost.

TABLE 34 : AVERAGE TRAVEL TIME IN SECONDS UNDER DIFFERENT INTERSECTION CONTROL DEVICES - INTERSECTION J

APPROACH	MOVEMENT	PEAK HOURS			OFF-PEAK HOURS		
		(1) TWO-WAY STOP SIGN	(2) SEMI-ACTUATED SIGNAL	DIFFERENCE	(1) TWO-WAY STOP SIGN	(2) SEMI-ACTUATED SIGNAL	DIFFERENCE
SALISBURY ST SOUTH LEG	STRAIGHT	16.7	20.9	+ 4.2	16.5	20.6	+ 4.1
	R.T.	20.8	22.1	+ 1.3	20.7	21.8	+ 1.1
	L.T.	19.7	21.6	+ 1.9	19.5	21.3	+ 1.8
SALISBURY ST NORTH LEG	STRAIGHT	17.2	20.8	+ 3.6	16.9	20.5	+ 3.6
	R.T.	19.3	21.1	+ 1.8	19.2	20.8	+ 1.6
	L.T.	20.5	21.6	+ 1.1	20.4	21.2	+ 0.8
STADIUM AVE EAST LEG	STRAIGHT	25.6	22.2	- 3.4	24.6	22.2	- 2.4
	R.T.	22.7	21.5	- 1.2	21.6	21.4	- 0.2
	L.T.	23.5	22.0	- 1.5	22.4	21.9	- 0.5
STADIUM AVE WEST LEG	STRAIGHT	26.0	22.5	- 3.5	25.6	22.3	- 3.3
	R.T.	22.7	21.8	- 0.9	22.3	21.6	- 0.7
	L.T.	21.9	21.3	- 0.6	21.5	21.1	- 0.4

(1) AND (2) : BOTH SIMULATION DATA

TABLE 35 : ESTIMATED 1978 TRAVEL DELAY* IN VEHICLE-HOURS FOR THE STOP SIGN AND SEMI-ACTUATED SIGNAL CONTROLS - INTERSECTION J

CONTROL DEVICE				
APPROACH	MOVEMENT	(1) TWO-WAY STOP	(2) SEMI-ACTUATED SIGNAL	DIFFERENCE
SALISBURY ST SOUTH LEG	STRAIGHT	1930	2410	+ 480
	R.T.	100	100	0
	L.T.	320	350	+ 30
SALISBURY ST NORTH LEG	STRAIGHT	1430	1730	+ 300
	R.T.	360	390	+ 30
	L.T.	100	110	+ 10
STADIUM AVE EAST LEG	STRAIGHT	1100	980	- 120
	R.T.	230	220	- 10
	L.T.	140	130	- 10
STADIUM AVE WEST LEG	STRAIGHT	1300	1130	- 170
	R.T.	620	600	- 20
	L.T.	310	300	- 10
TOTAL		7,940	8,450	+ 510

* : PERIOD COVERED FROM 6:00 AM TO 6:00 PM
 (1) AND (2) : BOTH SIMULATION DATA

CHAPTER 5 ACCIDENT ANALYSIS

Assurance of minimum interference between conflicting vehicular flows ranks as a prime traffic engineering objective. Intersection collisions historically have been a high proportion of the total accident tally. A study in Skokie, Illinois, for example, found 34 percent of all accidents occurred at the crossing of two major routes with an additional 17 percent at the intersection of a major with a local and eight percent at two locals (50). Overall, 59 percent of the Skokie area accidents involved intersections. Nationally, approximately one quarter of all accidents take place at road intersections (51).

The effect of traffic control signals on intersection accidents has been widely documented. However, the overall results of these studies vary considerably and are often contradictory. In some studies, the total number of accidents has decreased, while in others an increase in accidents has been reported. Nevertheless, the data from research on the subject does support certain conclusions.

It appears that intersections with low traffic volume, low accident frequency, or simple intersection layout are likely to have an increase in accidents after traffic control signals are installed. On the other hand, conditions that appear to be favorable for improved accident experience after signalization include large traffic volumes,

existing high accident frequencies, and complex intersections with five or more approaches.

These conclusions are based on results of studies made on the signalization of two-way STOP intersections. Although less research has been done on the effects of installing traffic signals at four-way STOP intersections, it does appear that the above conclusions pertain to these intersections as well.

The relationship between signalization and an increase in accidents at intersections with certain characteristics should be used by the traffic engineer in his argument to the political powers and general public against installing signals at these locations. However, the converse of this correlation can also be used as justification for removing signals. A recent study in Terre Haute, Indiana concluded that there will NOT be a significant increase in the number of accidents after the removal of a traffic control signal (52). Before and after accident data at five intersections where signals had been removed were obtained and only one intersection showed a significant change (decrease) in the number of accidents after the removal of the signals. The study also recommended wide publicity of signal removal in order to better prepare drivers for the change in operation at such intersections.

In this research, detailed accident data at study locations for the years 1976 to 1978 were obtained for all the intersections except the intersection of State Street and Airport Road. The accident record of that particular intersection was not available and thus it was not included in the accident analysis.

For the purpose of this study, those accidents that occurred at or near the intersection because of a driver's or pedestrian's failure to obey the traffic control device, or that occurred because of the presence of the control device at the intersection (e.g., rear-end accident in queue behind stop line), were included in the analysis. The police department's record did include as intersection accidents a few midblock collisions such as parked car accidents that had occurred within 200 feet of the intersection. They do not provide a measure of intersection safety with respect to a particular control device and as such, were not included in the analysis.

A complete summary of the accident data and a collision diagram was prepared for each of the study intersections. Using this information, the satisfaction of accident warrant for signal installation was reviewed. The possible countermeasures that would reduce the number and severity of accidents were identified. Jointly with the analysis results from the last chapter, an appropriate control device was then recommended for each location. In the final part of this chapter, by way of a set of accident evaluation factors, a single figure of merit for accidents at each intersection was presented based on its accident history.

Intersection A: 4th Street and Brown Street

The collision diagram covering the years 1976 to 1978 is shown in Figure 8. All the symbols used in this and those following are illustrated in Figure 9. A complete summary of the accident data is presented in Table 36.

FIGURE 8 : COLLISION DIAGRAM - INTERSECTION A

Path of moving motor vehicle
Pedestrian path
Fatal
Non-fatal
Rear-end collision
Parked vehicle
Fixed object
Overtaken
Out of control
Sideswipe

FIGURE 9 : LEGEND TO COLLISION DIAGRAM

TABLE 35 : ACCIDENT SUMMARY - 4TH STREET AND BROWN STREET
(PERIOD COVERED : JAN. 1976 TO DEC. 1978)

TIME OF DAY	NO. OF ACCIDENTS	ACCIDENT TYPE	NO. OF ACCIDENTS
6 A.M.-10 A.M.	0	SIDESWIPE	5
10 A.M.- 4 P.M.	4	REAR-END	2
4 P.M.- 7 P.M.	3	RIGHT ANGLE	0
7 P.M.-12 MID.	0	LEFT TURN	0
12 MID.- 6 A.M.	0	PEDESTRIAN	0
	-----	OTHER	0
TOTAL	7		TOTAL 7

WEATHER	NO. OF ACCIDENTS	TIME OF YEAR	NO. OF ACCIDENTS
CLEAR	6	WINTER (DEC.-FEB.)	0
FOG	0	SPRING (MAR.-MAY)	2
RAIN	1	SUMMER (JUNE-AUG.)	3
SNOW	0	FALL (SEP.-NOV.)	2
	-----		-----
TOTAL	7		TOTAL 7

PAVEMENT	NO. OF ACCIDENTS	ACCIDENT SEVERITY	NO. OF ACCIDENTS
DRY	6	FATAL INJURY	0
ICY	0	NON-FATAL INJURY	0
WET	1	PROPERTY DAMAGE ONLY	7
	-----		-----
TOTAL	7		TOTAL 7

YEAR	NO. OF ACCIDENTS	DIRECTION OF APPROACH	NO. OF VEHICLES
1976	3	NORTH	0
1977	2	SOUTH	10
1978	2	EAST	2
	-----	WEST	2
TOTAL	7		TOTAL 14

TYPE OF VEHICLES	NO. OF VEHICLES
PASSENGER CARS	14
COMMERCIAL VEHICLES	0

TOTAL	14

Seven accidents occurred in the three-year period and 70 percent of them were sideswipe accidents. The left turn maneuver made from the right lane of the one-way street (4th Street) caused this particular accident pattern. It was recommended that solid-white channelizing lines be installed and symbol arrows be used to guide and regulate traffic. This would substantially reduce the interlane weaving movements and thus reduce the number of high sideswipe accidents.

The one rear-end accident on 4th Street may have been caused by the unwarranted signal. The removal of the traffic signal should eliminate this type of accident. The best control device at the intersection from a safety point of view is STOP-sign control on Brown Street. The installation of a temporary flashing beacon may be desirable upon removal of the traffic signal.

Interaction B: Union Street and 6th Street

Figure 10 shows the collision diagram and Table 37 summarizes the accident data at this intersection. Sixteen (16) accidents occurred in the three years. The dominant types of accident were right angle and rear-end. No fatal or injury accident was found in the study period.

The right angle accidents accounted for 50 percent of the total accidents occurring at the intersection. This percentage is extraordinarily high for a signalized intersection as it is generally believed that traffic control signals do reduce right angle accidents. Since good visibility of the signals was provided on both streets, the probable cause of these right angle accidents is concerned with the traffic signal itself.

FIGURE 10 : COLLISION DIAGRAM - INTERSECTION B

TABLE 37 : ACCIDENT SUMMARY - UNION STREET AND 6TH STREET
(PERIOD COVERED : JAN. 1976 TO DEC. 1978)

TIME OF DAY	NO. OF ACCIDENTS	ACCIDENT TYPE	NO. OF ACCIDENTS
6 A.M.-10 A.M.	2	SIDESWIPE	0
10 A.M.- 4 P.M.	7	REAR-END	6
4 P.M.- 7 P.M.	2	RIGHT ANGLE	8
7 P.M.-12 MID.	4	LEFT TURN	1
12 MID.- 6 A.M.	1	PEDESTRIAN	0
	-----	OTHER	1
TOTAL	16		-----
		TOTAL	16

WEATHER	NO. OF ACCIDENTS	TIME OF YEAR	NO. OF ACCIDENTS
CLEAR	10	WINTER (DEC.-FEB.)	2
FOG	0	SPRING (MAR.-MAY)	3
RAIN	4	SUMMER (JUNE-AUG.)	5
SNOW	2	FALL (SEP.-NOV.)	6
	-----		-----
TOTAL	16	TOTAL	16

PAVEMENT	NO. OF ACCIDENTS	ACCIDENT SEVERITY	NO. OF ACCIDENTS
DRY	10	FATAL INJURY	0
ICY	2	NON-FATAL INJURY	0
WET	4	PROPERTY DAMAGE ONLY	16
	-----		-----
TOTAL	16	TOTAL	16

YEAR	NO. OF ACCIDENTS	DIRECTION OF APPROACH	NO. OF VEHICLES
1976	6	NORTH	7
1977	6	SOUTH	8
1978	4	EAST	0
	-----	WEST	19
TOTAL	16		-----
		TOTAL	34

TYPE OF VEHICLES	NO. OF VEHICLES
PASSENGER CARS	32
COMMERCIAL VEHICLES	2

TOTAL	34

First, as stated in the traffic volume and travel time-delay study, this traffic signal is in fact an unwarranted signal. The high disobedience rate (which was the sole cause for right angle accidents) of the traffic signal not only supports this conclusion but also clearly indicates the adverse effect of unwarranted signal control. Second, as mentioned before, progressive movement on Union Street was seriously disrupted by this signal because of lack of coordination with the traffic signal located approximately 800 feet upstream.

The above discussion is also pertinent to the explanation of the causes for rear-end accidents. The vehicles which are in the end of a platoon that released by the upstream signal usually are unable to clear this intersection in the green time provided. Being in the platoon, they tend to push the yellow light and even run the red light. For those that "hit the brake" to come to a quick stop, a rear-end accident is most likely to occur.

The existing traffic signal appears to not be contributing to traffic safety at this intersection. STOP signs on 6th Street should provide improved safety. Accident reduction as well as delay reduction could be expected under two-way STOP control. Here again, the installation of a temporary flashing beacon upon removal of the traffic signal may be desirable.

Intersection C: Union Street and 26th Street

Figure 11 shows the collision diagram and Table 38 summarizes the accident data at this intersection. Four accidents occurred in each of the three years studied and one quarter of the total accidents were Injury accidents. Rear-end and left turn type accidents

FIGURE 11 : COLLISION DIAGRAM - INTERSECTION C

TABLE 38 : ACCIDENT SUMMARY - UNION STREET AND 26TH STREET
(PERIOD COVERED : JAN. 1976 TO DEC. 1978)

TIME OF DAY	NO. OF ACCIDENTS	ACCIDENT TYPE	NO. OF ACCIDENTS
6 A.M.-10 A.M.	2	SIDESWIPE	1
10 A.M.- 4 P.M.	4	REAR-END	6
4 P.M.- 7 P.M.	4	RIGHT ANGLE	1
7 P.M.-12 MID.	0	LEFT TURN	4
12 MID.- 6 A.M.	2	PEDESTRIAN	0
		OTHER	0
	-----		-----
TOTAL	12		TOTAL 12

WEATHER	NO. OF ACCIDENTS	TIME OF YEAR	NO. OF ACCIDENTS
CLEAR	11	WINTER (DEC.-FEB.)	2
FOG	0	SPRING (MAR.-MAY)	4
RAIN	0	SUMMER (JUNE-AUG.)	3
SNOW	1	FALL (SEP.-NOV.)	3
	-----		-----
TOTAL	12		TOTAL 12

PAVEMENT	NO. OF ACCIDENTS	ACCIDENT SEVERITY	NO. OF ACCIDENTS
DRY	9	FATAL INJURY	0
ICY	2	NON-FATAL INJURY	3
WET	1	PROPERTY DAMAGE ONLY	9
	-----		-----
TOTAL	12		TOTAL 12

YEAR	NO. OF ACCIDENTS	DIRECTION OF APPROACH	NO. OF VEHICLES
1976	4	NORTH	0
1977	4	SOUTH	5
1978	4	EAST	12
		WEST	8
	-----		-----
TOTAL	12		TOTAL 25

TYPE OF VEHICLES	NO. OF VEHICLES
PASSENGER CARS	21
COMMERCIAL VEHICLES	4

TOTAL	25

respectively accounted for 50 and 33 percent of the total accidents occurring at the intersection.

The existing traffic control signal, which was found to be an unwarranted signal in the previous chapter, undoubtedly is responsible for the rear-end accidents. In addition, the poorly maintained pavement channelizing lines for the left turn pocket on the west approach cause the rear-end accident between through vehicle and the slowly moving or stopping left-turning vehicle.

This unwarranted signal also possibly caused disobedience of the intersection control and some of the resulting right angle accidents and left turn accidents between traffic from 26th Street and through traffic on Union Street.

A STOP sign on 26th Street with perhaps a flashing control beacon should reduce accidents at this intersection.

Intersection D: Teal Road and 30th Street

The collision diagram is shown in Figure 12 and the accident data is summarized in Table 39. Only two accidents occurred in the three-year period and both of them were involved with left-turning vehicles from the east approach.

The accident experience at this intersection is lower than the requirements stated in the MUTCD for signal installation. The accident record indicated that both accidents occurred solely due to driver's failure to yield right-of-way. Field observation also showed that adequate sight distance exists on both intersecting streets.

FIGURE 12 : COLLISION DIAGRAM - INTERSECTION D

TABLE 39 : ACCIDENT SUMMARY - TEAL ROAD AND 30TH STREET
(PERIOD COVERED : JAN. 1976 TO DEC. 1978)

TIME OF DAY	NO. OF ACCIDENTS	ACCIDENT TYPE	NO. OF ACCIDENTS
6 A.M.-10 A.M.	1	SIDESWIPE	0
10 A.M.- 4 P.M.	0	REAR-END	0
4 P.M.- 7 P.M.	0	RIGHT ANGLE	0
7 P.M.-12 MID.	1	LEFT TURN	2
12 MID.- 6 A.M.	0	PEDESTRIAN	0
		OTHER	0
	-----		-----
TOTAL	2		TOTAL 2

WEATHER	NO. OF ACCIDENTS	TIME OF YEAR	NO. OF ACCIDENTS
CLEAR	2	WINTER (DEC.-FEB.)	1
FOG	0	SPRING (MAR.-MAY)	0
RAIN	0	SUMMER (JUNE-AUG.)	0
SNOW	0	FALL (SEP.-NOV.)	1
	-----		-----
TOTAL	2		TOTAL 2

PAVEMENT	NO. OF ACCIDENTS	ACCIDENT SEVERITY	NO. OF ACCIDENTS
DRY	2	FATAL INJURY	0
ICY	0	NON-FATAL INJURY	0
WET	0	PROPERTY DAMAGE ONLY	2
	-----		-----
TOTAL	2		TOTAL 2

YEAR	NO. OF ACCIDENTS	DIRECTION OF APPROACH	NO. OF VEHICLES
1976	1	NORTH	0
1977	0	SOUTH	1
1978	1	EAST	2
		WEST	1
	-----		-----
TOTAL	2		TOTAL 4

TYPE OF VEHICLES	NO. OF VEHICLES		
PASSENGER CARS	3		
COMMERCIAL VEHICLES	1		

TOTAL	4		

Intersection F: Indiana State Road 26 and Creasy Lane

Figure 13 shows the collision diagram and Table 40 summarizes the accident data at this intersection. Twelve (12) accidents occurred in the three-year period and 58 percent of them were right angle accidents.

The MUTCD states that, in order to warrant a signal installation, five or more accidents must have happened at the location within a 12-month period and those accidents have to be of the type that are normally preventable by a signal. In the last year, 1978, there were five accidents at this intersection, including three right angle accidents (one was an injury accident), one left turn accident and one sideswipe. The sideswipe accident happened because of a weaving movement which, in fact, was caused by a left-turning vehicle from the south approach. All these five accidents are types susceptible of correction by traffic signal control. Thus, a traffic signal is justified at this intersection on the accident warrant. This further supports the conclusion in the previous chapter.

Under signal control (with an exclusive left turn phase, like the one utilized in simulation), the right angle and left turn conflicts should be expected to decrease. The variable initial and gap reduction features associated with the 350-foot detector setback will help to reduce possible rear-end accidents which often accompany signal control.

Finally, it should be noted that the accident summary indicated that 33 percent were night accidents. Street lighting or clearly

FIGURE 13 : COLLISION DIAGRAM - INTERSECTION F

TABLE 40 : ACCIDENT SUMMARY - S.R. 26 AND CREASY LANE
(PERIOD COVERED : JAN. 1976 TO DEC. 1978)

TIME OF DAY	NO. OF ACCIDENTS	ACCIDENT TYPE	NO. OF ACCIDENTS
6 A.M.-10 A.M.	4	SIDESWIPE	1
10 A.M.- 4 P.M.	2	REAR-END	2
4 P.M.- 7 P.M.	1	RIGHT ANGLE	7
7 P.M.-12 MID.	4	LEFT TURN	2
12 MID.- 6 A.M.	1	PEDESTRIAN	0
		OTHER	0
	-----		-----
TOTAL	12		TOTAL 12

WEATHER	NO. OF ACCIDENTS	TIME OF YEAR	NO. OF ACCIDENTS
CLEAR	12	WINTER (DEC.-FEB.)	2
FOG	0	SPRING (MAR.-MAY)	1
RAIN	0	SUMMER (JUNE-AUG.)	2
SNOW	0	FALL (SEP.-NOV.)	7
	-----		-----
TOTAL	12		TOTAL 12

PAVEMENT	NO. OF ACCIDENTS	ACCIDENT SEVERITY	NO. OF ACCIDENTS
DRY	11	FATAL INJURY	0
ICY	1	NON-FATAL INJURY	2
WET	0	PROPERTY DAMAGE ONLY	10
	-----		-----
TOTAL	12		TOTAL 12

YEAR	NO. OF ACCIDENTS	DIRECTION OF APPROACH	NO. OF VEHICLES
1976	2	NORTH	10
1977	5	SOUTH	0
1978	5	EAST	9
		WEST	5
	-----		-----
TOTAL	12		TOTAL 24

TYPE OF VEHICLES	NO. OF VEHICLES
PASSENGER CARS	21
COMMERCIAL VEHICLES	3

TOTAL	24

visible delineation markings should be installed to improve the visibility of the intersection,

Intersection G: Wiggins Street and Salisbury Street

Figure 14 shows the collision diagram and Table 41 summarizes the accident data at this intersection. Twenty-four (24) accidents happened in the three-year period and two-thirds of them were right angle accidents. The injury accidents were 42 percent of total accidents.

An increasing trend in the number of accidents is found in Table 41. In 1976, only three accidents occurred at the intersection. But in 1978, 12 accidents were recorded - a threefold increase. Of those 12 accidents, nine were the right angle type. Also noted was that 80 percent of the injury accidents belonged to the right angle category.

Field observation indicated that parked vehicles on both sides of Wiggins Street constituted severe sight obstructions. The resulting poor sight distance on both streets may have been a major cause for the high number of right angle accidents. In addition, minor-street vehicles who entered the intersection by accepting inadequate gaps usually caused weaving movements on the major street. These weaving movements in turn were responsible for the major street sideswipe accidents.

According to the MUTCD, this intersection satisfies the accident warrant for signal installation.

FIGURE 14 : COLLISION DIAGRAM - INTERSECTION G

TABLE 41 : ACCIDENT SUMMARY - WIGGINS STREET AND SALISBURY STREET
(PERIOD COVERED : JAN. 1976 TO DEC. 1978)

TIME OF DAY	NO. OF ACCIDENTS	ACCIDENT TYPE	NO. OF ACCIDENTS
6 A.M.-10 A.M.	1	SIDESWIPE	3
10 A.M.- 4 P.M.	11	REAR-END	1
4 P.M.- 7 P.M.	8	RIGHT ANGLE	16
7 P.M.-12 MID.	2	LEFT TURN	2
12 MID.- 6 A.M.	2	PEDESTRIAN	0
		OTHER	2
	-----		-----
TOTAL	24	TOTAL	24

WEATHER	NO. OF ACCIDENTS	TIME OF YEAR	NO. OF ACCIDENTS
CLEAR	21	WINTER (DEC.-FEB.)	6
FOG	0	SPRING (MAR.-MAY)	4
RAIN	2	SUMMER (JUNE-AUG.)	6
SNOW	1	FALL (SEP.-NOV.)	8
	-----		-----
TOTAL	24	TOTAL	24

PAVEMENT	NO. OF ACCIDENTS	ACCIDENT SEVERITY	NO. OF ACCIDENTS
DRY	15	FATAL INJURY	0
ICY	3	NON-FATAL INJURY	10
WET	6	PROPERTY DAMAGE ONLY	14
	-----		-----
TOTAL	24	TOTAL	24

YEAR	NO. OF ACCIDENTS	DIRECTION OF APPROACH	NO. OF VEHICLES
1976	3	NORTH	15
1977	9	SOUTH	8
1978	12	EAST	0
	-----	WEST	26
TOTAL	24	TOTAL	49

TYPE OF VEHICLES	NO. OF VEHICLES
PASSENGER CARS	42
COMMERCIAL VEHICLES	7

TOTAL	49

Intersection H: Fowler Avenue and Salisbury Street

The collision diagram is shown in Figure 15 and the accident data is summarized in Table 42. In the three-year period, 23 accidents happened at this intersection and nearly 90 percent of them were right angle accidents. As to accident severity, approximately half of the accidents were injury accidents.

The sight distance on the south approach is very poor because of the curved east leg. However, on the north approach, no significant sight obstruction is present. Interestingly, accident data indicated that 80 percent of the right angle accidents were involved with the southbound traffic from the north approach. The possible reason for this were that the traffic volume on the north approach was twice as much as that on the south approach, and that the drivers on the south approach were more cautious due to the sight restriction.

The accident data clearly indicates the urgent need for a traffic control signal. As mentioned before, this signal should be interconnected with any traffic signal at intersection G and two other adjacent signals on the major streets.

Intersection I: Grant Street and North Street

The collision diagram is shown in Figure 16 and the accident summary is presented in Table 43. It should be noted here that the traffic signal at this intersection has been changed from the regular "stop and go" operation to flashing operation since the summer of 1978. No accidents were recorded after the change. The accident data presented here thus pertains to traffic signal control only, although

FIGURE 15 : COLLISION DIAGRAM - INTERSECTION H

TABLE 42 : ACCIDENT SUMMARY - FOWLER AVENUE AND SALISBURY STREET
(PERIOD COVERED : JAN. 1976 TO DEC. 1978)

TIME OF DAY	NO. OF ACCIDENTS	ACCIDENT TYPE	NO. OF ACCIDENTS
6 A.M.-10 A.M.	3	SIDESWIPE	2
10 A.M.- 4 P.M.	6	REAR-END	0
4 P.M.- 7 P.M.	8	RIGHT ANGLE	20
7 P.M.-12 MID.	3	LEFT TURN	0
12 MID.- 6 A.M.	3	PEDESTRIAN	0
		OTHER	1
	TOTAL 23		TOTAL 23
WEATHER	NO. OF ACCIDENTS	TIME OF YEAR	NO. OF ACCIDENTS
CLEAR	19	WINTER (DEC.-FEB.)	5
FOG	0	SPRING (MAR.-MAY)	7
RAIN	3	SUMMER (JUNE-AUG.)	6
SNOW	1	FALL (SEP.-NOV.)	5
	TOTAL 23		TOTAL 23
PAVEMENT	NO. OF ACCIDENTS	ACCIDENT SEVERITY	NO. OF ACCIDENTS
DRY	19	FATAL INJURY	0
ICY	2	NON-FATAL INJURY	11
WET	2	PROPERTY DAMAGE ONLY	12
	TOTAL 23		TOTAL 23
YEAR	NO. OF ACCIDENTS	DIRECTION OF APPROACH	NO. OF VEHICLES
1976	9	NORTH	15
1977	7	SOUTH	6
1978	7	EAST	25
		WEST	0
	TOTAL 23		TOTAL 46
TYPE OF VEHICLES	NO. OF VEHICLES		
PASSENGER CARS	46		
COMMERCIAL VEHICLES	0		
	TOTAL 46

FIGURE 16 : COLLISION DIAGRAM - INTERSECTION I

TABLE 43 : ACCIDENT SUMMARY - GRANT STREET AND NORTH STREET
(PERIOD COVERED : JAN. 1976 TO DEC. 1978)

TIME OF DAY	NO. OF ACCIDENTS	ACCIDENT TYPE	NO. OF ACCIDENTS
6 A.M.-10 A.M.	4	SIDESWIPE	2
10 A.M.- 4 P.M.	3	REAR-END	3
4 P.M.- 7 P.M.	4	RIGHT ANGLE	2
7 P.M.-12 MID.	1	LEFT TURN	3
12 MID.- 6 A.M.	0	PEDESTRIAN	1
		OTHER	1
	TOTAL 12		TOTAL 12

WEATHER	NO. OF ACCIDENTS	TIME OF YEAR	NO. OF ACCIDENTS
CLEAR	9	WINTER (DEC.-FEB.)	3
FOG	0	SPRING (MAR.-MAY)	5
RAIN	2	SUMMER (JUNE-AUG.)	2
SNOW	1	FALL (SEP.-NOV.)	2
	TOTAL 12		TOTAL 12

PAVEMENT	NO. OF ACCIDENTS	ACCIDENT SEVERITY	NO. OF ACCIDENTS
DRY	8	FATAL INJURY	0
ICY	1	NON-FATAL INJURY	2
WET	3	PROPERTY DAMAGE ONLY	10
	TOTAL 12		TOTAL 12

YEAR	NO. OF ACCIDENTS	DIRECTION OF APPROACH	NO. OF VEHICLES
1976	5	NORTH	9
1977	3	SOUTH	9
1978	4	EAST	4
	TOTAL 12	WEST	2
			TOTAL 24

TYPE OF VEHICLES	NO. OF VEHICLES
PASSENGER CARS	20
COMMERCIAL VEHICLES	4
	TOTAL 24

the study period does extend to the end of 1978.

Twelve (12) accidents occurred at the intersection during the three-year period. Two of them were injury accidents with one involving a pedestrian. The accidents which occurred exhibit no pattern which can be attributed to type of control at the intersection. Some of the three rear-end collisions may have resulted from quick stops made for the signal but there is no evidence which confirms this. The one fact which is encouraging is that no accidents occurred at this intersection in 1978 after its conversion to two-way STOP control of the minor streets. This indicates that traffic signals would not be warranted because of accident experience.

Intersection J: Salisbury Street and Stadium Avenue

Figure 17 shows the collision diagram and Table 44 summarizes the accident data at this intersection. Fourteen (14) accidents occurred in the three-year period and 70 percent of them were right angle accidents. The accidents resulting in personal injury accounted for nearly half of the total accidents and 83 percent of them fell in the right angle category. It was also noted that no accident was recorded in 1976. The 14 accidents were evenly spread over 1977 and 78.

In the previous chapter, the continuing use of the current two-way STOP control was found to be warranted because the intersecting volumes did not satisfy a warrant in the MUTCD for the installation of traffic signal control. It appears, however, that the accident data might warrant a signal installation because seven accidents occurred in the last year, 1978. These seven accidents included four right angle

FIGURE 17 : COLLISION DIAGRAM - INTERSECTION J

TABLE 44 : ACCIDENT SUMMARY - SALISBURY STREET AND STADIUM AVENUE
(PERIOD COVERED : JAN. 1976 TO DEC. 1978)

TIME OF DAY	NO. OF ACCIDENTS	ACCIDENT TYPE	NO. OF ACCIDENTS
6 A.M.-10 A.M.	4	SIDESWIPE	0
10 A.M.- 4 P.M.	6	REAR-END	1
4 P.M.- 7 P.M.	2	RIGHT ANGLE	10
7 P.M.-12 MID.	2	LEFT TURN	3
12 MID.- 6 A.M.	0	PEDESTRIAN	0
		OTHER	0
	TOTAL 14		TOTAL 14
WEATHER	NO. OF ACCIDENTS	TIME OF YEAR	NO. OF ACCIDENTS
CLEAR	12	WINTER (DEC.-FEB.)	6
FOG	0	SPRING (MAR.-MAY)	3
RAIN	1	SUMMER (JUNE-AUG.)	3
SNOW	1	FALL (SEP.-NOV.)	2
	TOTAL 14		TOTAL 14
PAVEMENT	NO. OF ACCIDENTS	ACCIDENT SEVERITY	NO. OF ACCIDENTS
DRY	6	FATAL INJURY	0
ICY	2	NON-FATAL INJURY	6
WET	6	PROPERTY DAMAGE ONLY	8
	TOTAL 14		TOTAL 14
YEAR	NO. OF ACCIDENTS	DIRECTION OF APPROACH	NO. OF VEHICLES
1976	0	NORTH	8
1977	7	SOUTH	6
1978	7	EAST	4
	TOTAL 14	WEST	11
			TOTAL 29
TYPE OF VEHICLES	NO. OF VEHICLES		
PASSENGER CARS	26		
COMMERCIAL VEHICLES	3		
	TOTAL 29		

accidents, two left turn accidents and one rear-end accident. The rear-end accident, as can be seen in the collision diagram, happened because the following vehicle lost its control on the icy pavement. The other six accidents are types susceptible of correction by traffic signal control.

The MUTCD accident warrant, however, also stated that a traffic signal installation based on accident experience should be done only if "adequate trial or less restrictive remedies with satisfactory observance and enforcement has failed to reduce the accident frequency." For this intersection, instead of a traffic signal, the following countermeasures were instituted in the belief that the completion of them would reduce the number and severity of accidents.

First, the sight distance at the intersection was improved. Field observation indicated that parked vehicles and trees on both sides of the Salisbury Street seriously obscured the sight distance of the minor street traffic. Parking space near the intersection which impaired sight distance when occupied has been eliminated, several of the offending trees have been cut and others trimmed.

Second, the size of the flashing beacons at the intersection was increased from eight-inch to 12-inch so as to make the control requirement more visible to approaching motorists.

Third, pavement conditions at the intersection were improved. STOP lines on Stadium Avenue as well as painted islands which narrowed the approach lanes in Stadium and all other intersection markings were repainted and widened with plans to maintain them well.

Finally, icy or wet pavement conditions which encourage accidents should be minimized. As shown in Table 44, approximately 60 percent

of the total accidents occurred on icy or wet pavement. Nearly half of the total accidents happened during the winter (December to February). This information indicates that slippery pavement possibly played an important role in accident occurrence. Appropriate treatments such as overlaying existing pavement with a better non-skid surface, providing adequate drainage, etc. should be carried out to prevent the slippery condition when wet. In winter, rapid snow removal and salting of icy pavement could be very helpful.

The actions which have been taken to reduce accidents should result in making this a safe intersection without traffic signals. Furthermore, since a majority of the accidents occurred under wet or icy conditions, it is probable that a signal would, in fact, not reduce right angle accidents and would substantially increase rear-end collisions.

Accident Evaluation Analysis

In order to obtain a quantitative means of comparing accident histories at intersections, Abramson developed an accident evaluation index and accident evaluation factors by using percentage distribution of accidents by type (53). Accident evaluation factors are multipliers that, when applied to an accident history profile for an intersection, yield a single figure of merit. His effort recognized the fact that accident frequency alone is not adequate and can be misleading in evaluating and comparing the effectiveness of traffic controls at intersections. The severity and type of accident should be incorporated in the analysis to obtain a more valid assessment of the role that

accidents play in the selection of appropriate control devices. For example, changing a traffic control, say from a sign to a signal, may in fact result in an increase in the frequency of accidents at the intersection. However, the change may still be accident warranted if the degree of severity is reduced. This would be reflected in a decreased total cost of accidents, if accident severity is appropriately considered in the cost assignments.

Various accident cost studies were reviewed in Abramson's study. A summary of them is given in Table 45. This Table shows the relevant accident severity cost figures which are generally comparable in that losses due to work time lost are included and the same discounting rate (four percent) has been used. Note, however, that the values quoted are not all updated to the present. Because we seek only general estimates, reflecting relative magnitudes, this disparity is not significant.

Utilizing the values in Table 45, Abramson derived a weighting value for each accident severity type. For a fatal accident the weight assignment was 50,000 per accident; for an injury accident the weigh was 2,500 per accident and for a PDO (property damage only) accident, 500 per accident. These values were then combined with the severity rate to obtain cost-per-accident values for accident categorized by type. The results are given in Table 46.

Five types of accidents are shown in Table 46. The accident evaluation indexes were obtained by multiplying the rates by the appropriate accident severity weights. These five accident categories were selected because it was felt that, if differences in signal

TABLE 45 : COST IN DOLLARS PER ACCIDENT AT FOUR PERCENT DISCOUNT RATE

STUDY	COST UNIT	ACCIDENT SEVERITY		
		FATAL	INJURY	PDO
WASHINGTON, D.C.	INVOLVEMENT	47,481	863	193
TEXAS	ACCIDENT	50,227	1,917	334
SOCIETAL(1)	ACCIDENT	234,960	11,200	500
NSC(2)	CASE	52,000	3,100	440
I.I.I.(3)	CASE	48,115	2,850	570

(1) : SOCIETAL COSTS OF MOTOR VEHICLE ACCIDENTS. NHTSA, APRIL 1972

(2) : NATIONAL SAFETY COUNCIL

(3) : INSURANCE INFORMATION INSTITUTE

SOURCE : REFERENCE (53)

TABLE 46 : SEVERITY RATES AND ACCIDENT EVALUATION INDEXES BY URBAN AND RURAL ACCIDENT TYPES

ACCIDENT TYPE	URBAN				RURAL			
	FATAL	INJURY	PDO	ACCIDENT EVALUATION INDEX	FATAL	INJURY	PDO	ACCIDENT EVALUATION INDEX
PEDESTRIAN	0.0188	0.5812	--	3,390.0	0.0727	0.9273	--	5,950.0
RIGHT ANGLE	0.0010	0.0700	0.9290	690.0	0.0059	0.1380	0.8551	1,120.0
REAR-END	0.0001	0.0070	0.9930	520.0	0.0014	0.0280	0.9705	630.0
LEFT TURN	0.0009	0.0630	0.9360	670.0	0.0041	0.0820	0.9139	870.0
ALL OTHERS	0.0012	0.0840	0.9150	730.0	0.0059	0.1180	0.8761	1,030.0

SOURCE : REFERENCE (53)

control type affect accidents, distinct differences in the distribution of these types of accidents will be observed. Such an analysis should then constitute a more detailed evaluation of the relation of accidents to traffic control changes than merely differences in the total number of accidents.

In order to simplify the computation, the indexes in Table 46 were transformed by Abramson into the following factors. For an urban intersection the factors were 6.5, 1.3, 1.0, 1.3, and 1.4 for pedestrian, right angle, rear-end, left turn, and other accidents respectively; for rural intersections, the factors were 9.4, 1.8, 1.0, 1.4, and 1.6 for pedestrian, right angle, rear-end, left turn, and other accidents respectively. These factors were intended to serve as a means for combining accident history distribution into a single figure of merit.

As an illustration, suppose the accident profiles for a common time period at two given urban intersections are 0, 3, 5, 2, and 2 (total = 12) and 2, 1, 3, 2, and 1 (total = 9) for pedestrian, right angle, rear-end, left turn, and all other accidents respectively. The two figures of merit are then

$$0(6.5) + 3(1.3) + 5(1.0) + 2(1.3) + 2(1.4) = 14.3$$

and

$$2(6.5) + 1(1.3) + 3(1.0) + 2(1.3) + 1(1.4) = 21.3$$

Thus, the accident impact appears more severe at the second intersection even though it has had fewer accidents.

These accident evaluation factors were applied to the accident records of the study intersections. For a common three-year period, the figures of merit for these intersections are given in Table 47. Intersections G and H appear to have the most severe accident impact. These two intersections were found from both volume and accident studies to warrant a change from two-way STOP to signal control. This accident severity analysis further indicates such action might be helpful relative to accidents.

Two signalized intersections B and I rank as the second most severe locations. These two intersections were found from the volume and accident studies to not have warrants for the current signal control. Very possibly, a change to STOP control would result in safer conditions at these two intersections.

The safety figure of merit at intersection D is very good. This, however, is attributable to the very low volumes of minor street traffic which used this intersection during the three-year accident period. The STOP control at this intersection during that period was obviously a safe one.

Intersection F has a moderate figure of merit value and, although warranting a traffic signal in 1978 because of traffic volume, did not have the volumes in 1976 and 77 to warrant more than a two-way STOP. Accidents at this intersection, however, did warrant traffic signal control in 1978.

Intersection J also has a moderate figure of merit but the accident analysis indicated a majority of the accidents resulted on wet and icy pavement and may not have been relative to the type of intersection control.

TABLE 47 : ACCIDENT EVALUATION (AS REPRESENTED BY FIGURE OF MERIT) OF THE STUDY INTERSECTIONS

INTERSECTION	CONTROL DEVICE	FIGURE OF MERIT
A - 4TH AND BROWN	TRAFFIC SIGNAL	7.0
B - UNION AND 6TH	TRAFFIC SIGNAL	19.1
C - UNION AND 26TH	TRAFFIC SIGNAL	13.5
D - TEAL AND 30TH	TWO-WAY STOP	2.6
F - S.R. 26 AND CREASY	TWO-WAY STOP	14.7
G - WIGGINS AND SALISBURY	TWO-WAY STOP	30.2
H - FOWLER AND SALISBURY	TWO-WAY STOP	29.4
I - GRANT AND NORTH	TRAFFIC SIGNAL	19.4
J - SALISBURY AND STADIUM	TWO-WAY STOP	17.9

Intersection A and C have low to moderate accident figures of merit even though they have no warrants for the existing signal control. This is undoubtedly the result of the very low volumes on the minor streets.

The Table also indicates that signalized intersections do not necessarily result in smaller figures of merit than STOP-sign controlled intersections. Once again, it is indicated that signals are not a cure-all for traffic or accident problems.

The above accident evaluation technique can best be used by traffic engineers to identify high-accident locations and to rank high-accident locations to determine the priority of implementing improvements. With more and more limited funds today, priority rating will undoubtedly help the traffic engineer to obtain the greatest overall benefit in accident reduction.

CHAPTER 6 RECOMMENDATIONS AND CONCLUSIONS

This research examined and evaluated the delay and accident frequency associated with traffic flow in the vicinity of STOP sign and signalized intersections. Since the traffic signal provides for dynamic intersection control, the general public has assumed it to be a panacea for all intersection traffic and safety problems. Thus, in many communities due to a lack of traffic engineering expertise and/or the existence of community pressure, traffic control signals have been installed at intersections where they are not warranted. The objective of this research was to determine the benefits and/or disbenefits of such signals.

A total of ten intersections were studied in this research to evaluate the performance of vehicles at different types of controls. Based upon the results, the most efficient control strategy for each study intersection is presented below:

Warranted Controls at the Study Intersections

Intersection A: 4th Street and Brown Street

The existing traffic signal at this location is unwarranted and should be discontinued. Two-way STOP signs on the minor street (Brown) would provide the most efficient control under the current traffic conditions. In order to reduce the number of the prevailing sideswipe accidents at this intersection, it is also suggested that solid-white

channelizing lines be installed on the approach to the intersection and symbol arrows be used on the pavement or overhead to guide traffic on 4th Street.

Intersection B: Union Street and 6th Street

Two-way STOP signs should replace the existing unwarranted traffic signal. Total intersection travel delays would be reduced and accident frequencies might be improved under two-way STOP control. It would be desirable to mark the north approach of the intersection for two lanes to minimize delays to through vehicles.

Intersection C: Union Street and 26th Street

A two-way STOP sign on the minor street (26th) is the most efficient control from the driver's point of view. The existing traffic signal is unwarranted and should be removed. The accident experience at this intersection should not be made worse by such action.

Intersection D: Teal Road and 30th Street

The semi-actuated signal installation, which replaced in May 1979 the original two-way STOP control at this intersection, is a more efficient control for the system movements in this area. The traffic signal at this location relieves the congested condition at the intersection of Teal and Concord, thereby improving traffic flow on Teal Road.

Intersection E: State Street and Airport Road

The traffic volumes at this intersection satisfy the warrant for signal installation. The existing four-way STOP signs should be

removed and replaced by a traffic signal. A simulation study indicated the most travel delay reduction would occur with fully actuated signals. Well-timed pedestrian signals are also recommended.

Intersection F: S.R. 26 and Creasy Lane

Both traffic volumes and accident experience warrant a signal installation at this location. A full-actuated traffic signal would provide the most efficient control. The installation of street lighting or clearly visible delineation markings is also recommended to improve the visibility of the intersection during night hours.

Intersection G: Wiggins Street and Salisbury Street

and

Intersection H: Fowler Avenue and Salisbury Street

Relatively high accident frequencies of the right angle type indicate the need for traffic signal installations at both intersections. The traffic volumes on the major and minor streets also exceed the required amounts for the traffic signal warrant. The recommended signal controllers should be interconnected. The signals should also be coordinated with the other two adjacent traffic signals (approximately 700 feet away) located at the intersections of Wiggins Street with Vine Street and Fowler Avenue with Vine Street.

Intersection I: Grant Street and North Street

Both traffic volumes and accident experience do not satisfy the warrants in the MUTCD for signal installation at this intersection. The conversion from regular signal control to flashing two-way STOP

control in the summer 1978 was justified. Two-way STOP control is currently the most efficient type of control at this intersection.

Intersection J: Salisbury Street and Stadium Avenue

Neither a traffic signal nor four-way STOP control is warranted at this intersection. The existing two-way STOP control on the minor street (Stadium) is the most efficient control. However, to reduce the relatively high accident occurrence, sight obstructions from the minor street should be minimized and skid resistant pavement in the intersection area should be provided.

Conclusions

A number of conclusions resulted from this research. The major findings may be summarized as follows:

Unwarranted Signal Installations

- (1) At every intersection investigated in this study, including one where a traffic signal became warranted in 1978 on the basis of traffic volumes, total delay to all motorists using the intersection was increased by the installation of a traffic signal versus two-way STOP control. This was found to be true even when a warranted signal with full-actuated controls and proper timing was used. The usual advantages of lesser delays provided by the signal for minor street traffic are in fact outweighed by delays to through traffic on the major street — with the result that overall traffic performance is degraded. At one intersection currently

operating with four-way STOP control and now warranting a signal, total delay to traffic was found to be less under traffic signals control.

- (2) The most detrimental effect of an unwarranted traffic signal is the substantial increase in travel delays. In the cases of intersections A, B, and C, cumulative travel delays from 3200 to 4200 vehicle-hours were wasted in 1978 by major street traffic due to the unwarranted signalized controls at these locations. At the low volumes at which each of the minor streets to these intersections operate, the increased delay to traffic on the minor streets under STOP sign control is not likely to be very much. The net travel time savings for all vehicles will be substantial.

At intersection I, the conversion from unwarranted traffic signal control to two-way STOP control saved 10,340 vehicle-hours in 1978 for all entering traffic.

The simulation study at intersection J clearly indicated that an unjustified conversion to a traffic signal would increase total intersection delay.

It should also be noted here that the above travel delay estimates are conservative values covering only the period of 6:00 a.m. to 6:00 p.m. and calculated on the base of 260 weekdays in a year. The actual travel delay caused by the unwarranted signals is higher.

- (3) Under unwarranted traffic signal control, not only is the delay to major flow increased but, sometimes, the minor flow

also suffers greater delay. At study intersection I, 2950 vehicle-hours of travel delay were wasted by the minor flow in 1978 because of the traffic signal control. The 2950 vehicle-hours of travel delay accounted for approximately 30 percent of the total intersection delay caused by the unwarranted traffic signal.

- (4) It is obvious that the increased total delay resulting from traffic signal control results in greater fuel consumption and increased air pollution. As the increased travel delay is typically many hundreds of hours per year, one can also be certain that an unwarranted traffic signal results in the waste of hundreds of gallons of fuel each year.

It should also be noted that if the unwarranted traffic signals are coupled with poor traffic operation such as improper timing, poor signal visibility, no coordination if in a signal system, etc., further degradation of intersection performance is probable.

Concluding Remarks

During this study, it also became clear that at intersections where a traffic signal is warranted by traffic volumes but where STOP signs are still the method of control traffic accidents will be a major factor in analysis of the proper type of control for the intersection. Intersections G and H, for example, had the highest figures of merit relative to accidents of all intersections studied and warranted the installation of traffic signals.

Factors other than traffic volumes and accidents may also provide warrants for a traffic signal. Intersection D, for example,

where neither volumes nor accidents warranted a single, did have a signal warranted because of revisions in traffic operations within a network of streets so as to relieve congestion and improve safety at adjacent intersections.

Recommended Additional Research

This research has only been able to look at the unwarranted traffic signal problem in one community and at only a limited number of such installations. More before and after studies of traffic delays and accidents at locations where an unwarranted traffic signal is installed to replace a STOP sign should be made. Such studies involving replacement of a traffic signal with STOP signs would also be appropriate.

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LIST OF REFERENCES

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