JOINT HIGHWAY RESEARCH PROJECT

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CORRELATION OF DESIGN AND
CONTROL CHARACTERISTICS WITH
ACCIDENTS AT RURAL MULTI-LANE
HIGHWAY INTERSECTIONS

Peter A. Van Maren

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Interim Report

CORRELATION OF DESIGN AND CONTROL CHARACTERISTICS WITH ACCIDENTS AT
RURAL MULTI-LANE HIGHWAY INTERSECTIONS

TO: J. F. McLaughlin, Director
Joint Highway Research Project

December 21, 1977
Revised July 22, 1980
Project: C-36-59Y

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

File: 8-5-25

The first Interim Report on the HPR Part II Study titled "Evaluation of Design and Control Alternatives to Improve Safety of Intersections of Multi-Lane Highways with Other Highways" is attached. The Report has been authored by Mr. Peter A. Van Maren, Graduate Instructor in Research on our staff, under the direction of Professor H. L. Michael. The Report is titled "Correlation of Design and Control Characteristics with Accidents at Rural Multi-Lane Highway Intersections".

This Report provides for fulfillment of objectives 1 and 2 of the research study as approved and provides information for use in others, especially the development of measures to improve safety at such intersections. This is also the Interim Report called for by Task 5 of the approved Work Plan for the Study covering Tasks 1 through 4. Work on these tasks was more rapidly conducted than anticipated through the availability of personnel and as a consequence is submitted about six months ahead of schedule. Work on other tasks is progressing as originally planned.

The Report is submitted as partial fulfillment of the objectives of the Study. Upon acceptance by the JHRP Board it will be forwarded for ISHC and FHWA review and comment and similar acceptance.

Respectfully submitted,

Harold L. Michael
Associate Director

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by

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Project No.: C-36-59Y

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and the

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The contents of this report reflect the views of the author who is responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

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16. Abstract Sixty-one rural multi-lane intersections throughout Indiana were studied. Thirty-nine intersections were randomly selected from all such intersections in the state and twenty-two were submitted by the Indiana State Highway Commission. Geometric, accident and traffic volume data were collected from each intersection. The average rural multi-lane highway intersection had four times the number of accidents than the average rural intersection. The following findings were made about the randomly selected rural multi-lane highway intersections: unsignalized intersections were found to have a lower accident rate, median barriers and large intersections were found to increase the accident rate, and as the size of stop sign on the minor road increased, accidents decreased. The following findings are applicable to high accident signalized multi-lane intersections: the presence of stop line pavement markings decreased the accident rate; route markers and/or signal ahead advance warning signs on the minor road reduced the right angle accident rate; and a horizontal curve on the major road and/or a skew of the two roadways were found to increase the accident rate considerably.			
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TABLE OF CONTENTS

	<u>Page</u>
LIST OF TABLES.	v
LIST OF FIGURES	vi
LIST OF DEVELOPED EQUATIONS	vii
ABSTRACT.	viii
CHAPTER I: INTRODUCTION AND OBJECTIVES	1
CHAPTER II: LITERATURE REVIEW.	3
Factors Influencing Accidents at Intersections	3
CHAPTER III: DATA COLLECTION	13
Selection of Intersections	13
Traffic Volume Data.	14
Accident Data.	15
Geometric Data	16
CHAPTER IV: ANALYSIS OF DATA	17
Intersection Characteristics	17
Accident Rates	22
Regression Analyses: Relationship Between Intersectional Accident Rates and Roadway Characteristics.	23
CHAPTER V: CONCLUSIONS	38
Suggestions for Implementation	40
BIBLIOGRAPHY.	42
APPENDICES.	46
Appendix A: Calculation of Major and Minor Road 24 Hour ADT	46
Appendix B: Intersections by Traffic Control and Number of Accidents.	49

TABLE OF CONTENTS (Continued)

	<u>Page</u>
Appendix C: Calculation of Conflict ADT	52
Appendix D: Intersection Transformed Accident Rates	55
Appendix E: Intersection Data	58

LIST OF TABLES

<u>Table</u>	<u>Page</u>
1 The Effect of Width of Median and Lighting Conditions on Accident Involvements.	7
2 The Effect of Degree of Horizontal Curve on Accident Rate.	7
3 Number of Total Accidents as a Function of ADT (All Random Intersections - 3 Year Period - 1974, 1975, 1976).	19
4 Number of Total Accidents as a Function of ADT (All 61 Intersections - 3 Year Period - 1974, 1975, 1976).	19
5 Number of Total Accidents as a Function of ADT (Nonsignalized Intersections - 3 Year Period - 1974, 1975, 1976).	20
6 Number of Total Accidents as a Function of ADT (All Flasher Intersections - 3 Year Period - 1974, 1975, 1976).	20
7 Number of Intersections as a Function of ADT (All Signalized Intersections - 3 Year Period - 1974, 1975, 1976).	21
8 List of Variables and Codes.	25
9 Simple Correlations Between Accidents/Million Conflicts and the 26 Independent Variables	31
 Appendix	
Table	
1A AADT for Suburban, Local, and Highways Roadways in Indiana.	48
1B Intersections by Traffic Control and Number of Accidents .	49
1D Intersection Transformed Accident Rates.	55
1E Intersection Data.	58

LIST OF FIGURES

<u>Figure</u>		<u>Page</u>
1	Accident Index by Alinement and Shoulder Width.	8
2	Effect of Control of Access on Accidents and Fatalities in Urban and Rural Areas	10
3	Multi-Lane Highways Investigated in Indiana	18

LIST OF DEVELOPED EQUATIONS

<u>Equation</u>		<u>Page</u>
1A	Total Accidents Per Million Conflicts Using All Random Intersections.	33
1B	Total Accidents Per Million Entering Vehicles Using All Random Intersections.	34
2	Total Accidents Per Million Conflicts Using ISHC Signalized Intersections.	35
3	Right Angle Accidents Per Million Conflicts Using ISHC Signalized Intersections	36

HIGHLIGHT SUMMARY

Divided highways were originally constructed to separate opposing traffic streams and reduce accidents. But in doing this, operational and design problems have occurred at their intersections with minor roads. This research investigated the relationship between accident rates at such intersections and the geometric and control features present.

This project studied sixty-one multi-lane intersections throughout Indiana. Thirty-nine intersections were randomly selected from all rural multi-lane intersections in the state and twenty-two were submitted by the Indiana State Highway Commission (ISHC). Geometric, accident and traffic volume data were collected for each intersection. The geometric data gathered for each intersection included: traffic control, the advance warning on the major and minor roads, the median width, the presence of stop line pavement markings, the shoulder width, the skew of the minor with the major road, the grade of the major road, the degree of horizontal curve, the relative elevation of the minor to the major road, the presence of left or right deceleration lanes, the size of median opening across the intersection, the distance from the minor stop line to the opposite side of the intersection, and the presence of a median barrier. The accident data were collected for the three year period of 1974, 1975, and 1976. A total of 1535 accidents resulted from this investigation.

Rural multi-lane highway intersections in Indiana were found to be a serious safety problem. The average multi-lane highway intersection has four times the number of accidents than the average rural intersection. The high accident signalized multi-lane intersections

submitted by the ISHC had 25 times the number of accidents per intersection as the average rural intersection.

For analysis, an accident rate using the number of accidents divided by the expected number of conflicts (conflict rate), in addition to the regular intersectional entering vehicle rate, was calculated. The conflict rate was found to better describe the accident potential of high accident locations than one utilizing the intersectional entering volume.

Three regression models were developed which correlated accidents per million conflicts (MC) to geometric and control characteristics of the intersections. One regression model correlated the accidents per million entering vehicles (MEV) to the geometric and control characteristics. The data set and accident type used in each operation was the following:

1. All random intersections and the total number of accidents.
2. The ISHC high accident signalized intersection list and their total number of accidents.
3. The ISHC high accident signalized intersection list and their right-angle accidents.

No one variable was found to consistently influence the accident rate in all the equations. But when combined with the other variables in the equations, several important observations could be made. This seems to substantiate the notion that many features of an intersection probably contribute to the cause of its accidents.

Based on the two regression equations developed from the randomly selected intersections, the following findings were made about rural intersections of a multi-lane highway in Indiana:

1. Unsignalized intersections were found to have a lower accident rate.
2. The accident rate increased at large non-signalized intersections. Large danger distances (the distance across the intersection) increased the accident rate.
3. Median barriers were found to increase the accident rate.
4. As the size of stop sign on the minor road increased the accident rate decreased

The following findings are applicable to high accident signalized multi-lane intersections.

1. The presence of major and minor road stop line pavement markings decreased the accident rate.
2. Route markers and/or signal ahead advance warning signs on the minor road reduced the right-angle accident rate, but route markers were found to reduce the right-angle accident rate more than signal ahead signs.
3. Both a horizontal curve on the major road and a skew of the two roadways were found to increase the accident rate.

CHAPTER I: INTRODUCTION

Fast and efficient transportation networks are demanded by today's mobile society. Highway intersections are a critical element in highway networks as they primarily determine the efficiency and capacity of each highway link. At the same time, at-grade highway intersections are a serious safety problem. In Indiana, approximately 36 percent of the total reported accidents occur at intersections. Right-angle accidents accounted for 49 percent of these accidents in 1975, of which 137 were fatal accidents (21)*.

Further evidence of the hazard caused at intersections is shown in a study on the State Route 52 bypass in Lafayette, Indiana when one researcher found 57 percent of the accidents taking place within 100 feet of an intersection, 65 within 200 feet, and 76 percent within 500 feet (35). In Oakland, California, 78 percent of the accidents were reported within or near intersections (15).

Even if an intersection does not have a long history of accidents, the public can become very vocal if there is only one severe accident. A decision to correct any intersection deficiencies, however, should be based on reliable evidence of the relationships between accidents and intersection characteristics - in particular, the geometric features of the intersection.

Originally, multi-lane highways were designed to provide a median between opposing directions of travel. An outgrowth of the increased construction of multi-lane highways without access control is design and operational problems at their intersections with other roadways.

The past several years, the Division of Traffic Engineering of the Indiana State Highway Commission (ISHC) has experimented with various control techniques - signing, marking, and signaling - at

*Numbers in parentheses refer to entries in the Bibliography.

intersections involving multi-lane highways. The results have failed to develop a combination of controls which adequately solves the intolerable high accident situation at some of the intersections. The Division also realized that other factors which they had not considered might affect the situation. Therefore, the ISHC has encouraged the Joint Highway Research Project management to investigate this situation and prompted this research project.

Objectives

The objectives of this research project are the following:

1. Evaluation of the seriousness of the rural multi-lane, cross-road intersection accident problem in Indiana.
2. To determine quantitatively the factors affecting accidents at such intersections and the levels of the factors which produce the lowest or "most optimal" accident rates. If these factors become known to highway engineers, then a policy toward utilizing them in present control and future design of multi-lane highway intersections can be realized.

This phase of this research investigated the highway factors which contributed to accidents. Included were roadway design factors and operational control factors. It is recognized that vehicle, driver, and environmental factors may also be important. They were not evaluated in this phase of the study because of the impossibility of obtaining reliable data on them over the accident history period investigated. They, however, were factors to be considered by the interdisciplinary team in that subsequent phase of this research.

CHAPTER II: LITERATURE REVIEW

Factors Influencing Accidents at Intersections

Before a reduction of accidents can be realized in any situation, the major factors contributing to their occurrence must be identified. The causes of accidents at intersections of multi-lane highways with minor roadways are probably as varied as the number of intersections. Basically they are the same areas as at other types of highway facilities: the driver, the vehicle, the roadway and the environment.

Highways should be designed so that a driver needs to make only one decision at a time and is never surprised by an unexpected situation where there is inadequate time for a decision. Accidents are more likely to occur where there are a number of things the driver must observe and where simultaneous reactions are required: the highway intersection is a prime example of this. Standardization plays an important role under such circumstances as the driver is made aware of what to expect.

A report by Johnson (24) determining the factors involved in accidents found that in 68 accidents studied, 289 contributing variables were identified, an average of 4.3 per case. This points out the fact that even with all the techniques available to them, traffic engineers will probably never be able to eliminate all traffic accidents.

The vehicle operator is undoubtedly the most important single component of the driving process (10) and also the most difficult to understand and control. In a 1968 study, improper driving was found to contribute to 90.6 percent of the nation's fatal accidents. Moreover, alcohol was reported to be a factor in nearly half of all fatal accidents.

In other studies, vehicle defects were found to be the cause of approximately 2 to 3 percent of the accidents in one study (1) and 9.3 percent in another (19). The most significant vehicle defects were defective brakes and improper lighting.

Generally, there is a relation between increased speed and accident rates until congestion slows down the traffic (4, 38, 39, 42, 46), although two studies found the number of accident involvements to be higher at low speeds than at moderately high speed (14, 37).

In a study of accidents at low frequency rural locations (36), a very significant correlation between the number of vehicle registrations per county and the number of accidents was found. Another analysis of vehicle accident rates at intersections showed them to be influenced in varying degrees by major and minor street volumes (43, 44). Use of such rates help in understanding average affects of a control change.

A study by Woo (50) on rural Indiana highways indicated that accident occurrences were related to the ADT and the total number of entrances per mile for certain volume ranges of traffic. Head (18) found that accident rates on low volume roads do not have a strong relationship with any roadway feature, but that accident rates increased with an increase in the number of commercial units adjacent to the section, the number of traffic signals, the number of intersections, average speed, average daily traffic and pavement width.

Another research group (25) concluded:

1. Four lane highways had higher accidents rates than two lane highways when there was no median and no access control.
2. Medians tended to decrease the number of accidents though the effect was not clearcut.
3. The number of one-vehicle accidents per million vehicle-miles (MVM) rate decreased with increasing ADT and the MVM rate for multi-vehicle accidents increased with increasing ADT.
4. The presence of the geometric elements (curves, grades, intersections, and structures) increased the accident rate on highways. The dominant element was intersections, which often gave accident rates three times as high as the rates on sections with none of the elements.

Research by Peterson on the State Route 52 Bypass (in Lafayette, Indiana) (35) established that for intersections, accidents per 100 million vehicles increased when: percent green time decreased; bypass, cross street, or total ADT increased; maximum approach speed increased; the number of intersection approaches increased; and total width of driveways within 200 feet of the intersection increased.

Cribbins and others (11) investigated accidents at signalized intersections of multi-lane highways with left-turn storage facilities and established the following factors important in predicting accidents: ADT of the minor road, the number of signalized intersections with storage per mile of study site, and the number of signalized intersections without storage per mile of study site. In another report on signalization, King (26) found there was no evidence that signalization by itself, would lead to a significant decrease in net accident-related disutility, especially for traffic signals not warranted by traffic volume.

In a study by Shaw (42), a rural accident rate (number of accidents per million vehicles) prediction equation found the most significant variable to be: total intersection weekday ADT. Other important variables reported were the number of approach lanes, the width of the approach roadway at the intersection, the approach volume per hour at the time the accident occurred, the weekday approach ADT plus the weekday opposing ADT, the ratio of the approaching volume per hour to the capacity of the approach direction, and the ratio of the opposing volume per hour to the capacity of the opposing direction.

A major problem at the intersection of multi-lane highways with minor roadways may be that cars entering from the minor roadway are not certain when an adequate gap exists in the far lanes of traffic. Drivers may consider stopping in the median to be unsafe, so try to go all the way across at one time. If their estimation then of an adequate gap is wrong, a serious accident can occur. This problem could be one of the factors contributing to the indication that an increase in traffic on the major facility has been found to cause little effect on the accident rate, but an increase in traffic volume,

or an increase in the percentage of traffic on the minor facility results in a rapid jump in the accident rate (29, 38).

In the design of multi-lane divided highways, the type and width of median is very important to the overall safety of the facility. A median should be at least 40 feet wide (20) for minimization of head-on collisions at high speeds. If the median must be narrow a barrier will eliminate head-on collisions but may damage the vehicle or cause the driver to lose control and become involved in an accident with traffic moving in the same direction. Although the severity is reduced, the number of accidents may increase (5, 32). Table 1 shows the effects of the width of median on four lane highways on accident involvements in day and night conditions.

The optimum shoulder width is commonly believed to be that width which permits the emergency parking of a vehicle without interference to traffic in the adjacent lanes. Studies in this area, however, have been far from conclusive. Billion (6) showed that sections with wide shoulders had much lower accident rates than with narrow shoulders. But Blensly and Head (8) reported an increase in accidents with an increase in shoulder width.

Research reveals that highways with sharp curves have more accidents than highways with curves less than three degrees (7, 38). Table 2 shows the effect of degree of horizontal curve on the accident rate developed in a 1951 study. Other studies find the accident rates to be highest on roads having a combination of sharp curves and steep grades (6, 7). See Figure 1.

Table 1. The Effect of Width of Median and Lighting Conditions on Accident Involvements

Median Width 4-Lane	Veh.-Mile	Total Accident Involvements	
		Number	Rate
<u>Day</u>			
< 15'	322,087,000	440	137
15-39'	484,970,000	928	191
> 40'	222,290,000	263	118
<u>Night</u>			
< 15'	130,874,000	433	331
15-39'	164,126,000	663	404
> 40'	43,368,000	168	387

Source: Accidents on Main Rural Highways Related to Speed, Driver and Vehicle, US DOT, FHWA, 1964 (2).

Table 2. The Effect of Degree of Horizontal Curve on Accident Rate

Degree of Curve	Accident Rate (Per Million-Veh.-Miles)
< 3°	1.37
3-5°	2.48
> 5°	3.86

Source: Kipp, O. L., "The Minnesota Road Survey", HRB Bulletin 38, Highway Research Board, pp. 68-72, 1951 (27).

Figure 1. Accident Index by Alinement and Shoulder Width

Source: Billion, C. E., and Stohner, W. R., "A Detailed Study of Accidents as Related to Highway Shoulders in New York State", HRB Proceedings, Highway Research Board, pp. 497-508, 1957.

Uniformity of vehicle operating speeds through intersections (low relative speeds between vehicles) appears to be more important than the absolute vehicle speed (2).

A study of rural highways indicated a variation of daytime accidents by type with traffic speed (2). The linear increase in the percentage of rear end involvements with increased speed was notable. Angle collisions also increased linearly, but at a relatively small rate, with increasing speed. Angle collisions were responsible for one third of the total accidents at speeds below 25 mph.

Many studies have investigated the effects of improved lighting at intersections. Thirty investigations (23) reported a decrease in accident experience and especially night time fatalities, under the improved conditions. These reports were composed of urban and rural locations in 16 states. Walker (48) found a 49% overall reduction in night accidents after lighting using a sample of 47 intersections.

Environmental factors have a largely nonquantifiable influence on accidents. Such factors include weather conditions and land use. Unrestricted land usage often results in decreasing the driver's sight distance and increasing the number of access points, thereby reducing the safe approach speed. Adverse weather conditions can cause slippery road surfaces and reduce driver visibility. The difficulty in quantifying this characteristic, however, was brought out by Levy (28) when he found little relationship between slippery wet pavement surfaces and accidents.

Control of access is one of the most important single factors in accident reduction. Michaels (31) found evidence of a linear relationship between accidents and the development of adjoining land. Cribbins (11) was even more definite on four lane divided highways: "as roadside development increases, and crossovers of any type are permitted, accidents will increase". Partial control has been found to be helpful in rural areas, but of far less value in urban areas, probably because the motorist gains a false sense of security and may not be prepared to cope with unexpected traffic conflicts. See Figure 2.

Figure 2. Effect of Control of Access on Accidents and Fatalities in Urban and Rural Areas

Source: The Federal Role in Highway Safety, House Document No. 93, 86th Congress, 1st Session.

Another study indicated that provisions for vehicles to make left turns off major routes might be an important design element affecting accidents. After left turn channelization was installed at 40 unsignalized urban and rural intersections along California highways, accidents were found to be reduced significantly (32).

The Federal Highway Administration and the National Highway Traffic Safety Administration found from a recent study (33) that for all types of intersections:

1. Intersections with an ADT greater than 15,000 and with obstructions within the standard 20 foot sight angle have 5.3 more accidents per year than do intersections that are unobstructed within that distance.
2. Intersections with opposing left turn facilities and an ADT between 10,000 and 20,000 had significantly more accidents than those without such lanes.
3. In high volume intersections ($ADT > 10,000$), sight distance should be maintained up to at least 100 feet from the stop limit lines. Clearance of obstructions within this range should be effective in reducing accidents. In intersections having an ADT below 5,000 the analysis revealed only marginal accident reduction as a result of clear leg-to-leg visibility.

The FHWA and NHTSA study added that to maintain the capacity of an intersection to carry the design flow of traffic, left-turn storage should not be eliminated; instead, it should be used only to increase capacity and not to serve as an accident-reduction measure. In fact, in intersections with a high accident rate, raised pavement markers in addition to existing striping of the left turn geometrics were suggested. Lastly, the investigation showed that three-phase signalization (left-turn phasing included), correlated with a reduction in the accident rate. Wu's findings (51) seemed to agree with the FHWA and NHTSA conclusions on visibility when he found that there was a significantly higher injury and property damage accident rate at four-legged signalized intersections (both urban and rural) with poor visibility than those with clear visibility.

Several researchers have concluded that the yield sign, as an intersection control, can be effective in many low volume situations. In the past, the two way stop sign has been installed along major routes to control intersecting local or collector streets. A California study of major and local type intersections at 150 locations along divided highways indicated (29):

1. Accident rates at intersections are much more sensitive to changes in minor road volume than in major road volume.
2. No direct relation exists between intersection accident rates and the sum of entering volumes.
3. Low cross road volume intersections have higher accident rates per cross road volume than do higher cross road volume intersections.
4. Evidence was found that cross road volumes above 2400 ADT produce high accident rates per cross road vehicle.

The Michigan State Highway Department has investigated the effect of a directional median crossover (40) to deal with the problem of left turns at the intersections of multi-lane highways and minor roadways. The crossover is constructed through the median approximately 300 feet beyond the major crossroad, and some or all of the left turning traffic are required to use the crossovers. The report found a four lane divided roadway and a 60' median as minimum requirements for the operation of directional crossovers, with a 72' median ideal. Driver confusion was experienced right after implementation, but a "fish hook" sign seemed to eliminate most of the problems. The directional crossovers had a significant effect in reducing the number of accidents, particularly right-angle accidents.

CHAPTER III: DATA COLLECTION

There are 800 miles of rural at-grade intersections of multi-lane highways with minor roadways in Indiana. They cover 48 counties and are present in all geographic areas of the state. A major task of this project was to determine which data to collect in order to economize on time and money. This chapter will describe the data collection techniques used in the investigation.

Selection of Intersections

In order to infer the results to intersections all over the state of Indiana, a random sample of intersections was required. A complete list of all the rural design multi-lane intersections in the state was compiled from the Indiana Accident System Maps. The recorded intersections were then classified into two lists, signalized and non-signalized intersections, to insure that a random sample would include a representative number of high volume intersections (the signalized intersections were assumed to be of higher volume than the non-signalized intersections). A rate of approximately 5.5:1 (non-signalized to signalized intersections) resulted and this was the ratio at which the intersections were chosen from the two lists.

There were approximately 400 intersections taken from the Accident System Maps, and a sample of about 40 intersections, or 10 percent of the total was considered adequate.

The number of intersections chosen from each highway was proportional to the length of that highway to all other dual lane highways in the state. In other words, the longer the highway, the more intersections that were chosen to represent it.

The total number of signalized and non-signalized intersections for each highway were selected in random order using a random number

table and it was in this order that they were considered for the final list of intersections. Next an investigation at each of the intersections was made to determine if the intersection was of rural design. If not, that intersection was crossed off and the next one in line was considered. This procedure was carried out until all the intersections were chosen.

The Indiana State Highway Commission (ISHC) also submitted 16 high accident multi-lane intersections and three off-ramp intersections of Interstate 465 (two diamond and one parclo interchanges) to study in the research. Each of the latter interchanges was considered as two intersections, resulting in a total ISHC contribution of twenty-two high-accident intersections.

The random sample of 39 and the ISHC list of 22 intersections resulted in a final total of 61 intersections which were studied in detail in this research.

Traffic Volume Data

Some traffic volume data for major approaches to the study intersections were available from the county traffic volume maps of the ISHC planning section. But in most cases these maps did not contain the volumes of the minor roads and in all cases did not have the turning movement counts. As a result, traffic volumes of the signalized intersections were obtained from recent traffic engineering studies made by ISHC at those intersections. All volumes at the non-signalized intersections were obtained from a two hour manual traffic count at each intersection.

Since these volumes were in terms of less than a 24 hour ADT, the counts were factored to ADT by using the appropriate factors from a study of Indiana roads by Michael (30) and then converted to the years 1974, 1975, and 1976 by factors developed from the records of automatic traffic recorders maintained by the planning division of the ISHC. Example calculations of this procedure can be found in Appendix A.

Accident Data

Accident data were obtained from the state police headquarters in the State Office Building in Indianapolis. Indiana state law mandates that written reports be filed by all drivers and the investigating officer involved in a motor vehicle accident involving death, injury to any person, or total property damage equal to 200 dollars or more (22). As a result, this is the most accurate source of accident data available. The officers' reports were considered to be more dependable, therefore most accident data was recorded from them.

The accident data were collected for the years 1974, 1975 and 1976 since at least three years are needed to get a stable accident history and yet still be current enough to evaluate the controls presently in service at the intersections. The 1975 and 1976 data were collected from the original report and most of 1974 were obtained from microfilm copies of the accident records.

The intersection accident data collected from the files described the light conditions (dawn, dark, daytime, and dusk), the road condition (wet, dry, snow and ice), the time and date, the accident type (rear end, turning movement, right angle, and others), and the severity of the accident (property damage, personal injury, and fatality). Of course the most important data included a description of the accident and the accident diagram.

Based on the 1535 accidents at the 61 intersections over the study period, the following percentages were developed:

1. 30.6% of the intersection accidents were right angle accidents, while 49.2% involved rear end collisions.
2. 77% of the accidents occurred during daylight hours.
3. 73% of the intersections accidents occurred under dry pavement conditions.
4. 66% of the accidents resulted in property damage only, and 33% involved personal injury. There were 17 fatalities.

Geometric Data

From the literature search, approximately 15 geometric characteristics of the intersections were chosen to be investigated. The data were collected from field observations and construction plans.

The degree of horizontal curve at the intersection, the relative elevation difference of the minor road to the major road, the grade of the major road, and the skew of the minor road to the major road were collected from the design plans of each intersection available at the ISHC in its Design Division.

Field observations at each site provided the following information (a measuring wheel was used in obtaining some of the measurements).

1. Traffic control.
(If the control was a stop sign, the size of the sign was recorded).
2. Advance warning on the major and minor roads.
3. Median width.
4. Pavement markings.
5. Shoulder width.
6. The presence of special lanes.
(Left turn lanes, deceleration lanes or acceleration lanes on the major road, and acceleration lanes in the median of the major road for vehicles turning left off the minor onto the major).
7. Size of the median opening.
(The distance between the medians on the major road).
8. "Danger" distance.
(The distance from the stop line of the minor, to the opposite side of the intersection).
9. Type of median.
(Curbed, median barrier, etc.)
10. Type of intersection.
(4-leg, diamond interchange, T-intersection, other).
11. Miscellaneous.
(Islands, rumble strips, etc. that are present at some of the intersections).

CHAPTER IV: ANALYSIS OF DATA

Intersection Characteristics

The 800 miles of dual-lane highways are in 48 counties of Indiana. Intersections in 30 of the counties were studied in this project. Figure 3 shows the locations of the highways in the state and illustrates the locations of the intersections.

The intersections investigated had a large range of entering volume ADT - from a low of 20 to a high of 15,530 for the minor road and 3,280 to 35,590 for the major road ADT. Appendix B has the intersections stratified by type of traffic control and also includes the number of total accidents for each of the 3 years of the study.

Tables 3 through 7 show the number of total accidents as a function of ADT. Table 3 represents the ten percent random sample of multi-lane highway intersections in Indiana. The seriousness of the accident problem at these intersections is illustrated very well under the column labeled "average number of accidents per intersection per year". A value of 10.3 accidents per intersection per year was found for intersections with a minor road ADT of greater than 2001, making these intersections unquestionably the most urgent situation. 3.2 accidents per intersection per year and .8 accidents per intersection per year for the intersections of 501 to 2000 ADT and less than 500 ADT, respectively, indicate a less obvious deficiency, but there is still much room for improvement. Tables 4 through 7 further substantiate the fact that no matter what the control present - stop sign, flasher, or signal - the intersections with greater than 2001 ADT are consistently the most dangerous.

Again, assuming the random sample represents 10% of the possible rural multi-lane highway intersections, all such intersections in the state had five percent of the state rural intersection collisions in

Figure 3. Multi-Lane Highways Investigated in Indiana

Table 3: Number of Total Accidents as a Function of ADT (All Random Intersections - 3 year period - 1974, 1975, 1976).

ADT Range (Minor Road) (1975)	Total Number of Intersections in Sample	Total Accidents	Average Number of Accidents Per Intersection Per Year
0-500	16	38	.8
501-2000	18	173	3.2
> 2001	5	155	10.3
Total	39	366	3.1

Table 4: Number of Total Accidents as a Function of ADT (All 61 Intersections - 3 year period - 1974, 1975, 1976).

ADT Range (Minor Road) (1975)	Total Number of Intersections in Sample	Traffic Control			Total Accidents
		Nonsignalized	Flasher	Signal	
0-500	16	16	0	0	38
501-2000	21	14	3	4	283
> 2001	24	4	4	16	1214
Total	61				1535

Table 5: Number of Total Accidents as a Function of ADT (All Nonsignalized Intersections - 3 year period - 1974, 1975, 1976).

ADT Range (Minor Road) (1975)	Total Number of Intersections in Sample	Total Accidents
0-500	16	38
501-2000	14	93
> 2001	4	153
Total	34	284

Table 6: Number of Total Accidents as a Function of ADT (All Flasher Intersections - 3 year period - 1974, 1975, 1976).

ADT Range (Minor Road) (1975)	Total Number of Intersections in Sample	Total Accidents
0-500	0	0
501-2000	3	38
> 2001	4	77
Total	7	115

Table 7: Number of Total Accidents as a Function of ADT (All Signalized Intersections - 3 year period - 1974, 1975, 1976).

ADT Range (Minor Road) (1975)	Total Number of Intersections in Sample	Accidents
0-500	0	0
501-2000	4	152
> 2001	16	984
Total	20	1136

1975. But these intersections constitute approximately one percent of the rural intersections in Indiana. This percentage of accidents (5%) may seem low, however, the average number of accidents per intersection per year for all rural intersections in Indiana in 1975 was .7 of an accident. This estimate was calculated from the number of rural intersection collisions in 1975 (21) and the number of rural intersections in Indiana (17). The 3.1 accidents per intersection per year found on rural multi-lane highways is over four times that of the average rural intersection in the state. There can be little doubt that intersections with rural multi-lane roadways are a significant safety problem in Indiana.

The high accident signalized locations submitted by the ISHC had an average of 17.7 accidents per intersection per year. This value by itself shows the seriousness of the safety problem at those intersections.

Accident Rates

For intersections, accident rates are usually calculated using the following equation (9):

$$\begin{array}{lcl} \text{rate per million} & \# \text{ of accidents (or injuries} & \\ \text{entering vehicles} & \text{in one year} & \text{or deaths)} \\ \text{(MEV)} & \text{24 hour intersectional} & \\ & \text{entering (vehicle) volume} & \end{array} \quad \begin{array}{l} \times 1 \text{ million} \\ \times 365 \end{array}$$

In this analysis, a volume termed the conflict ADT was utilized in order to arrive at an estimate of the conflicts caused by the major and minor roads. The new rate was used because if the major road had a very high ADT and the minor road a very low ADT, the total intersectional ADT would be high, but would not reflect the true possibility of conflicts, or accidents. Appendix C describes the conflict ADT in detail. Therefore, an accident rate used here in addition to the regular accident rate (MEV) was the rate per million conflicts (MC).

Since accidents are infrequent events which follow a Poisson distribution (16), and there were some intersections with no accidents over the study period, a value of 1.0 was added to each calculated

accident rate and then the square root of this value was taken. In statistical analysis this procedure is referred to as transforming the accident rates. Finally the rate was averaged over the study period to get a more representative accident rate for each intersection. The accident rate had no replicates, therefore normality and homogeneity tests were not possible for the data (3). The data was assumed to be both normal and homogeneous.

Accident rates using conflicts were developed for the accident types of:

1. right-angle accidents
2. rear-end accidents
3. total accidents

Accident rates using entering vehicle volume were also calculated for total accidents.

The dependent variable or accident rate was calculated using an average rate over the three year study period (as explained above) except for two intersections. When a three year rate is used, the independent variables or intersection characteristics must be consistent over that period. But the intersection of SR 63 with SR 163 in Vermillion County was under construction in 1974 and for US 31 at SR 38 the traffic control was changed from flashers to signals back to flashers in 1975. Therefore in these two situations, a two year average rate was calculated.

The average transformed accident rates of all the intersections are listed in Appendix D.

Regression Analyses: Relationship Between Intersectional Accident Rates and Roadway Characteristics

The equations developed in this study do not attempt to explain the frequencies of accidents at intersections of multi-lane highways and minor roadways by taking into account all variables which might have some effect. Environmental (weather, land use, etc.), driver, and vehicle characteristics at the intersections were not included. On the other hand, all highway facility and control characteristics which might

have an effect on accident rates were considered. A few, however, could not be included because their use did not occur in sufficient numbers (rumble strips, right turn islands, very wide medians, etc.) to permit analysis.

Since accidents are infrequent events, it is obvious that an equation cannot predict the exact number of accidents which will occur at a given intersection during a given time period. The best it can do is predict the mean number of expected accidents at an average intersection type during an extended time period.

The major objective of the regression equations was to investigate how differences in one variable (roadway and control characteristics) affect another variable (accident rate). In this case the dependent variable was the accident rate and the independent variables were the roadway and control characteristics. The analysis began with four dependent variables (as explained earlier) and 26 independent variables.

Table 8 is a list of the independent variables used in the analysis together with the codes utilized.

Because of the large number of independent variables available for the regression and relatively few (in relation to the number of independent variables) number of intersections, the following procedure was followed in obtaining the regression equations:

1. From the correlation matrix between the dependent and independent variables, choose the highest correlated independent variables so their number is at most one less than the number of data points involved.
2. Run stepwise regression to get the best linear model using only those variables which added significantly to the R^2 .
3. Force in the variables which are dummy variables associated with variables already in the equation.
4. Try interaction and quadratic terms on non-dummy variables.
5. Calculate C_p values and use the computer package DRRSQU

Table 8: List of Variables and Codes

<u>Variable Description and Code</u>				
Traffic Control				
X_1	X_2	X_3	X_4	
1	0	0	0	stop, no yield or flasher
0	1	0	0	stop, with yield and/or flasher
0	0	1	0	timed signal
0	0	0	1	actuated signal
0	0	0	0	timed signal with stop light

Presence and size of stop sign

X_5	X_6	
0	0	no stop sign (signalized)
1	1	28" stop
1	2	30" stop
1	3	32" stop
1	4	34" stop
1	5	36" stop
1	6	38" stop
1	7	40" stop

Stop or signal ahead as advance warning on minor road

$X_7 = 0$	not present
$X_7 = 1$	present

Route marker as advance warning on minor road

$X_8 = 0$	not present
$X_8 = 1$	present

Overhead bar as advance warning on major road

$X_9 = 0$	not present
$X_9 = 1$	present

Table 8 Continued

Stop or signal ahead and route marker or only a route marker as advance warning on major road

$X_{10} = 0$ not present

$X_{10} = 1$ present

Median width (X_{11})

0 = 0-10' 4 = 41-50'

1 = 11-20' 5 = 51-60'

2 = 21-30' 6 = 61-70'

3 = 31-40' 7 = > 70'

Minor road stop line pavement markings

$X_{12} = 0$ not present

$X_{12} = 1$ present

Major and minor road stop line pavement markings

$X_{13} = 0$ not present

$X_{13} = 1$ present

Shoulder width (X_{14})

0 = 0 to $\leq 4'$ 2 = >10' to $\leq 12'$

1 = >4' to $\leq 10'$ 3 = > 12'

Skew (X_{15})

0 = $\geq 85^\circ$ to $\leq 90^\circ$ 4 = $\geq 65^\circ$ to $< 70^\circ$

1 = $\geq 80^\circ$ to $< 85^\circ$ 5 = $\geq 60^\circ$ to $< 65^\circ$

2 = $\geq 75^\circ$ to $< 80^\circ$ 6 = $< 60^\circ$

3 = $\geq 70^\circ$ to $< 75^\circ$

Grade (Absolute value) (X_{16})

0 = > 0 to $\leq .05\%$ 4 = > 1.00 to $\leq 1.50\%$

1 = > .05 to $\leq .10\%$ 5 = > 1.50 to $\leq 2.00\%$

2 = > .10 to $\leq .50\%$ 6 = $\leq 2.00\%$

3 = > .50 to $\leq 1.00\%$

Table 8 Continued

Horizontal curve (X_{17})

$0 = 0^\circ$ $2 = > 1^\circ \text{ to } \leq 2^\circ$
 $1 = > 0^\circ \text{ to } \leq 1^\circ$ $3 = \quad \quad \quad > 2^\circ$

Relative elevation (X_{18})

$0 = > (-2') \text{ to } \leq (-1')$ $3 = > 0' \text{ to } \leq 1'$
 $1 = > (-1') \text{ to } \leq (0')$ $4 = > 1' \text{ to } \leq 2'$
 $2 = 0'$ $5 = \quad \quad \quad > 2'$

Left turn lane on major road

$X_{19} = 0$ not present
 $X_{19} = 1$ present

Right turn deceleration lane on major road

$X_{20} = 0$ not present
 $X_{20} = 1$ present

Right turn acceleration lane on major road

$X_{21} = 0$ not present
 $X_{21} = 1$ present

Left turn acceleration lane on major road

$X_{22} = 0$ not present
 $X_{22} = 1$ present

Size of median opening (X_{23})

$0 = 31-40'$ $4 = 71-80'$
 $1 = 41-50'$ $5 = 81-90'$
 $2 = 51-60'$ $6 = > 90'$
 $3 = 61-70'$

Table 8 Continued

Danger Distance

X_{24}	X_{25}	
0	0	not applicable (signalized)
1	1	< 70'
1	2	70-80'
1	3	81-90'
1	4	91-100'
1	5	101-110'
1	6	> 110'

Median barrier

$X_{26} = 0$	not present
$X_{26} = 1$	present

to determine if any variables could be eliminated. The C_p value indicates the correct number of independent variables (P) in the equation based on contribution to the R^2 value, where DRRSQU gives all possible regression equations using the same data set. Reference 33 discusses the C_p concept. In the development of these regression equations there really was not an estimate of true error so the C_p values were used as a relative measure in relation to each other.

Appendix E lists the variables as coded for each intersection.

Following issuance of the draft of this report in December 1977 and its review, questions were raised concerning the finding from the data that for the ISHC high-accident intersections actuated signals had a greater accident rate than intersections with fixed time signals. A close check of the data and intersection operations indicated that at some of the actuated signal controlled intersections the actuation was not operational for prolonged periods during the accident history period. This situation was found to be so prevalent that the accident data for actuated signals could not be considered reliable. As a consequence the variable of fixed time signal (X_3) and actuated signal (X_4) had to be eliminated for the high accident intersection analysis. Coding was redone at these 14 intersections to make all X_4 codes X_3 so that X_3 now indicated that a traffic signal, fixed time or actuated, was present at the intersection. With this action the code X_4 was eliminated at the high accident intersections and all regression and correlation calculations at these intersections were performed without an X_4 variable.

Many stratifications of the data by intersection type, accident type and control type were carried out in attempting to get the most information from the regression equations. The four equations in this report are the result of those trials. A reasonable regression equation resulted for each of the following:

<u>Group</u>	<u>Index</u>	<u>Dependent Variable</u>
All random intersections	Y_{1A}	$\sqrt{\text{total acc/MC} + 1}$
All random intersections	Y_{1B}	$\sqrt{\text{total acc/MEV} + 1}$
ISHC list of high accident signalized intersections	Y_2	$\sqrt{\text{total acc/MC} + 1}$
ISHC list of high accident signalized intersections	Y_3	$\sqrt{\text{right-angle acc/MC} + 1}$

Simple correlations were calculated between the dependent and independent variables. These values are given in Table 9.

Major relationships based on the simple correlations (the effect of the independent variables acting alone) for the random and ISHC high accident signalized intersections are as follows:

All Random Intersections

<u>Simple Correlation Coefficient</u>	<u>Comment</u>
-0.76773 (X_5)	The presence of non-signalized intersection will decrease the accident rate(Y_{1B}).
+0.56025 (X_{26})	The presence of a median barrier will increase the accident rate(Y_{1A}).
-0.54003 (X_6)	As the size of stop signs increase, the accident rate(Y_{1B}) will decrease.
+0.43007 (X_{23})	As the size of median opening increases, the accident rate(Y_{1B}) will increase.

ISHC High Accident Signalized Intersections

<u>Simple Correlation Coefficient</u>	<u>Comment</u>
-0.62763 (X_{13})	Minor stop line pavement markings will decrease the accident rate(Y_2).
-0.60037 (X_{22})	The presence of left turn acceleration lanes on the major road will decrease the accident rate(Y_2).
-0.55051 (X_{18})	As the elevation of the minor road relative to the major road increases, the accident rate(Y_2) will decrease.
-0.50311 (X_{21})	The presence of right turn acceleration lanes on the major road will decrease the accident rate(Y_2).
+0.50277 (X_{17})	As the horizontal curve increases, the accident rate(Y_2) will increase.
-0.48746 (X_{20})	The presence of right turn deceleration lanes on the major road will decrease the accident rate(Y_2).

Table 9: Simple Correlations Between Accident Rates and the Twenty-Six Independent Variables.

Independent Variable	Random Total Total/MC (39 sites)	Random Total Total/MEV (39 sites)	ISHC-Signalized Total/MC (14 sites)	ISHC-Signalized Right-Angle/MC (14 sites)
X ₁	.11172	-.06312	*	*
X ₂	-.53371	-.63258	*	*
X ₃	.47186	.66621	*	*
X ₄	.30539	.58210	*	*
X ₅	-.47201	-.76773	*	*
X ₆	-.31314	-.54003	*	*
X ₇	.44457	.42739		
X ₈	.00744	.21868		
X ₉	*	*		
X ₁₀	.32495	.70176	-.07386	-.22140
X ₁₁	-.05023	-.06841	-.42664	-.63257
X ₁₂	.12578	-.04833	-.41473	-.20128
X ₁₃	.44943	.57751	.23898	-.07577
X ₁₄	.10617	.10873	-.37348	-.39722
X ₁₅	.15325	.19838	-.06305	-.08827
X ₁₆	-.11699	-.06266	-.62763	-.52061
X ₁₇	-.16335	-.11267	-.48131	-.46104
X ₁₈	-.09099	-.20166	.16512	.13378
X ₁₉	.38938	.34527	.18456	.22772
X ₂₀	.36630	.34751	.50277	.70614
			-.55051	-.51727
			-.24331	-.38579
			-.48746	-.61675

Table 9 Continued.

Independent Variable	Random Total Total/MC (39 sites)	Random Total Total/MEV (39 sites)	ISHC-Signalized Total/MC (14 sites)	ISHC-Signalized Right-Angle/MC (14 sites)
X ₂₁	.26524	-.26169	-.50311	-.41343
X ₂₂	.14990	.16133	-.60037	-.60620
X ₂₃	.20142	.43007	.19438	.03859
X ₂₄	-.44345	-.62922	*	*
X ₂₅	-.30445	-.47307	*	*
X ₂₆	.56025	.11873	*	*

* Variable was constant in that stratification.

-0.48131 (X_{14})	Major and minor road stop line pavement markings will decrease the accident rate(Y_2).
-0.42664 (X_8)	The presence of a route marker as advance warning on the minor road will decrease the accident rate(Y_2).
-0.41473 (X_9)	An overhead bar as advance warning on the major road will decrease the accident rate(Y_2).

Similar effects on the right-angle accident rate were found for each of the above factors. The effect of a horizontal curve, a route marker as advance warning on the minor road, or the presence of right turn deceleration lanes on the major road appear to be greater for right-angle accidents, while the effect of an overhead bar as advance warning on the major road has less effect.

Total Accidents per Million Conflicts Using Random Intersections

The dependent variable, its mean value, and range is as follows:

<u>Variable</u>	<u>Minimum</u>	<u>Mean</u>	<u>Maximum</u>	<u>Range</u>
$\bar{Y}_{1A}$	1.0	2.6667	8.0	7.0
$\bar{Y}_{1A}^2$ -1	0.0	6.1113	63.0	63.0

The observations on the independent variables came from 39 intersections. Six independent variables were selected by the process described earlier as the best predictors.

$$Y_{1A} = 3.6535 - .3353 X_5 - .2585 X_6 + 1.0627 X_{20} - 1.2568 X_{24} \\ + .0126 X_{25} + 3.2689 X_{26} \quad (\text{Equation 1A})$$

The R^2 value for this equation is .645, indicating that 64.5 percent of the variance of Y_{1A} can be explained by the six variables.

The adjusted R^2 is .578, which is another measure of goodness of fit accounting for the number of observations relative to the number of independent variables. The equation for the regular R^2 equals the residual sum of squares divided by the total sum of squares, and the adjusted R^2 equals one minus the error mean square divided by the total mean square.

For equation 1A, the standard deviation of Y given these independent variables, $S_{Y.X}$, is equal to 1.1304, and the coefficient of variation $100(S_{Y.X}/\bar{Y}_{1A})$ is equal to 42.4 percent. This coefficient indicates the relative residual variations and can be used to compare the relative confidence of the final four regression equations. Higher percentages indicate higher relative residual variations and lower confidence.

A 95 percent confidence interval about the mean accident rate was calculated for the prediction equation. It shows the range of mean values within which there is a 95 percent certainty of the true mean value of accident rate.

The 95 percent confidence interval about the mean accident rate for Equation 1A was calculated as follows:

$$[\bar{Y}_{1A} \pm t_{.025, n} \sqrt{\frac{SY}{n}}]^{2-1} = [2.6667 \pm 2.022 \sqrt{\frac{1.2787}{39}}]^{2-1} = (4.293, 8.197)$$

The highest simple correlation, or R, between the independent variables was +.5977. The other simple correlations were considerably less, which means that correlations between the independent variables did not in anyway influence the final equations.

From Equation 1A, three variables were found to decrease the accident rate and three to increase the rate. The presence of a stop sign (or a non-signalized intersection) (X_5) and the other dummy variable with it, an increasing size of stop sign (X_6), decreased the accident rate. The presence of a danger distance, which in effect means a non-signalized intersection (X_{24}) also decreased the accident rate. But the dummy variable with X_{24} , the size of danger distance (X_{25}), increased the accident rate as the danger distance increased. The two most important factors increasing the accident rate were the presence of a right turn deceleration lane on the major road (X_{20}) and the presence of a median barrier (X_{26}).

When the variables of equation 1A were correlated with the regular accident rate, i.e., the rate per million vehicles entering, the R^2 was .771. The higher R^2 is probably caused by the fact that for randomly selected intersections the minor roads had low volumes, and therefore the conflict ADT was low and not as appropriate. But later it will be shown that for high volume minor roads the conflict ADT rate did a better job as the dependent variables than the intersectional volume rate.

Because the accident rate per million vehicles entering as the dependent variable resulted in a better prediction equation for this data set, a complete analysis was carried out.

Total Accidents per Million Entering Vehicles Using All Random Intersections

The dependent variable, its mean value, and range is as follows:

<u>Variable</u>	<u>Minimum</u>	<u>Mean</u>	<u>Maximum</u>	<u>Range</u>
$\bar{Y}_{1B}$	1.0	1.2386	2.3	1.3
$\bar{Y}_{1B}^2 - 1$	0.0	.5341	5.3	5.3

The observations on the independent variables came from 39 intersections. Six independent variables were selected by the process described earlier as the best predictors.

$$Y_{1B} = 1.6684 - .3102 X_5 - .4915 X_6 + .1382 X_{20} + .1637 X_{21} \\ - .2602 X_{24} + .00262 X_{25} \quad (\text{Equation 1B})$$

For this equation, R^2 equals .809, (adjusted R^2 equals .774), the standard deviation $S_{Y.X}$ equals .1466, and the coefficient of variation $100(S_{Y.X}/\bar{Y}_{1B})$ equals 11.8 percent. The 95 percent confidence interval about the mean accident rate is given as:

$$[1.2386 \pm 2.022 \sqrt{\frac{.0215}{39}}]^2 - 1 = (.4188, .6540)$$

The highest simple correlation between the independent variables was +.6666 which means that correlations between the independent variables did not in any way influence the final equation.

As in the previous equation, Equation 1B finds the presence of a stop sign (or nonsignalized intersection) (X_5) and the increasing size of stop sign (X_6) decreasing the accident rate. Also the presence of danger distance, i.e., a nonsignalized intersection (X_{24}) was found to decrease the accident rate, and the dummy variable with it, the size of the danger distance (X_{25}), increasing the accident rate as the distance increases. Another indication that the accident rate increases with the size of intersection was seen with the presence of right turn deceleration lanes (X_{20}).and right turn acceleration lanes (X_{21}) increasing the accident rate.

Total Accidents per Million Conflicts Using ISHC Signalized Intersections

The dependent variable, its mean value, and range is as follows:

<u>Variable</u>	<u>Minimum</u>	<u>Mean</u>	<u>Maximum</u>	<u>Range</u>
$\bar{Y}_2$	2.8	4.5786	7.0	4.2
$\bar{Y}_2^2 - 1$	6.8	19.9636	48.0	41.2

The observations on the independent variables came from 14 intersections. Five independent variables were selected as the best predictors by the process described earlier.

$$Y_2 = 5.2719 - .9719 X_{12} - 2.1403 X_{13} + .3061 X_{15} + 1.5281 X_{17} + .6840 X_{21} \quad (\text{Equation 2})$$

For this equation, R^2 equals .643 (adjusted R^2 equals .420) the standard deviation $S_{Y.X}$ equals .9682 and the coefficient of variation 100 ($S_{Y.X}/\bar{Y}_2$) equals 21.1 percent.

The 95 percent confidence interval about the mean is given as

$$[4.5786 \pm 2.145 \sqrt{\frac{.9375}{14}}]^2 - 1 = (15.189, 25.355)$$

The highest simple correlation between the independent variables was +.7500 which means that correlation between the independent variables did not in any way influence the final equation.

In Equation 2, the presence of minor road stop line pavement markings alone (X_{12}) or the presence of major and minor road stop line pavement markings (X_{13}) were found to decrease the accident rate. As the skew of the intersection (X_{15}) and horizontal curve on the major road (X_{17}) increases, the accident rate shows a positive correlation and therefore will increase. As in a previous equation, the presence of right turn acceleration lanes on the major road (X_{21}) was shown to increase the accident rate.

The R^2 for this equation was .322 when the regular accident rate was used, indicating the accident rate involving the conflict ADT was a superior dependent variable for high volume signalized intersections.

Right-Angle Accidents per Million Conflicts Using ISHC Signalized Intersections.

The dependent variable, its mean value, and range is as follows:

<u>Variable</u>	<u>Minimum</u>	<u>Mean</u>	<u>Maximum</u>	<u>Range</u>
$\bar{Y}_3$	1.7	3.2000	5.6	3.9
$\bar{Y}_3^2 - 1$	2.9	9.2400	31.4	28.5

The observations on the independent variables came from 14 intersections. Seven independent variables were selected as the best predictors by the process described earlier.

$$Y_3 = 4.2254 - .3015 X_7 - 1.222 X_8 - 2.1030 X_{12} - .3433 X_{13} \\ + 1.3746 X_{17} + .7776 X_{19} - .7060 X_{22} \quad (\text{Equation 3})$$

For this equation, R^2 equals .920, (adjusted R^2 equals .827) the standard deviation $S_{Y.X}$ equals .4074, and the coefficient of variation $100(S_{Y.X}/\bar{Y}_3)$ equals 12.7 percent.

The 95 percent confidence interval about the mean accident rate is given as

$$[3.2000 \pm 2.145 \sqrt{\frac{.1660}{14}}]^2 - 1 = (7.800, 10.789)$$

The highest simple correlation between the independent variables was + .5774 which means that correlation between the independent variables did not in any way influence the final equation.

Equation 3 shows five variables decreasing and two variables increasing the right-angle accident rate. Both the stop or signal ahead (X_7) and route marker (X_8) as advance warning on the minor road were found to decrease the right angle accident rate, although the route marker lowered the accident rate more than the stop or signal ahead sign. As in Equation 2, the presence of minor road stop line pavement markings alone, (X_{12}) or the presence of major and minor road stop line pavement markings (X_{13}) were found to decrease the accident rate. As the horizontal curve of the major road (X_{17}) increases, the coefficient showed the right angle accident rate to increase. The presence of left turn lanes on the major road (X_{19}) caused an increase while left turn acceleration lanes on the major road (X_{22}) caused a decrease in the right-angle accident rate.

CHAPTER V: CONCLUSIONS

This study investigated the possibility of determining the design and control features which reduce accidents at intersections of multi-lane highways in Indiana. To this end, four regression models were developed which correlated accident rates to geometric and control characteristics of the intersections.

During the development of the accident statistics and the analysis of these intersections, several additional findings were made.

1. The number of accidents increased as the minor road ADT increased.
2. Rear-end collisions accounted for 49.2% of all accidents on the multi-lane highway intersections studied, and right-angle collisions, 30.6%.
3. Approximately 75% of the accidents occurred in daylight and on dry pavement.

The hazard at rural multi-lane highway intersections in Indiana was found to be serious. The average multi-lane highway intersection has at least four times the number of accidents than the average rural intersection in Indiana. The high accident signalized multi-lane intersections submitted by the ISHC had at least 25 times as many accidents per intersection as the average rural intersection. Also, even though these intersections constitute only one percent approximately, of the rural intersections, they had five percent of the accidents.

In the analysis phase, an accident rate using the number of accidents divided by the expected number of conflicts (conflict rate) in addition to the regular intersectional entering vehicle rate, was calculated. The expected number of conflicts in any eight second interval was the product of the probability that a vehicle was in the specified conflict region during that interval. This probability was then multiplied times all eight second intervals in a day. The conflict rate was found to better describe the accident potential of high accident locations than one utilizing the intersectional entering volume.

Based on the two regression equations developed from the randomly selected intersections, the following findings were made about rural intersections of a multi-lane highway with a crossroad in Indiana:

1. Unsignalized intersections were found to have a lower accident rate; this might be due to a lower volume on the minor road at these intersections, but it may also be that signalization often increases accidents.
2. Evidence showed that the accident rate increased at large unsignalized intersections. Large danger distances (the distance across the intersection) increased the accident rate.
3. Median barriers were found to increase the accident rate considerably. However, they may be warranted to reduce the severity of accidents.
4. As the size of stop sign on the minor road increased, the accident rate decreased.

The following findings are applicable to high accident signalized multi-lane intersections.

1. The presence of stop line pavement markings on both the major and minor roads decreased the accident rate.
2. Route markers and/or signal ahead advance warning signs on the minor road reduced the right-angle accident rate, but route markers were found to reduce the right angle accident rate more than the signal ahead signs.
3. The following factors were found to increase the accident rate:
 - a. A horizontal curve on the major road.
 - b. A skew of the two roadways.
4. Although the presence of left turn lanes and right turn acceleration lanes on the major road were correlated with an increase in some accident rates, the small sample (14 intersections) and other factors at these intersections (high left turn volume and narrow medians for many of the locations) makes

any conclusion questionable. A similar finding is applicable to the correlation of left turn acceleration lanes on the major road and a decrease in right angle accidents. The correlations are applicable to the fourteen intersections.

It is interesting to note that the width of median did not enter any of the equations developed. The simple correlations of the accident rates with the width of median were very low, averaging approximately $-.07$. A possible reason for this was that about 70% of the random intersections studied had width of medians between 30 and 60 feet, therefore the data might not have had adequate range for evaluation of this factor. Only one of the high accident intersections had a median width greater than 60 feet and all but three had median widths less than 50 feet.

As noted above, the median factor and possibly some others, as well as the full range of values for some factors did not prove to have high correlations with any of the accident rate variables. Some of this result can undoubtedly be assigned to lack of adequate data. The number of intersections investigated were few and the range of values for some factors did not cover all typical uses adequately. As a result it cannot be stated that those factors or all their possible ranges which did not correlate with accident rates are truly not correlated.

Suggestions for Implementation

On the basis of the investigation in this report, the following suggestions for implementation can be made:

Rural multi-lane highway intersections

1. Control

- A. Install large size stop signs on the minor roads of non-signalized intersections.

2. Design

- A. Decrease the danger distance (the distance from the minor stop line across non-signalized intersections) of the intersection. This can be accomplished by moving the stop line on the minor road closer to the through lanes on the major road. This should not be achieved by decreasing the median width.

High accident rural signalized multi-lane intersections

1. Control

- A. Paint minor and major stop line pavement markings.
- B. Route markers and signal ahead signs as the advance warning signs on the minor roads should be installed.

2. Design

- A. Intersections should not occur at or near a horizontal curve or be at a skew.

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APPENDICES

APPENDIX A

CALCULATION OF MAJOR AND MINOR ROAD
24 HOUR ADT

APPENDIX A: CALCULATION OF MAJOR AND MINOR ROAD 24 HOUR ADT

1. Calculation of 24 hour ADT from the two hour manual traffic counts: (Reference 30 was used in obtaining the monthly factor, the daily factor, and the hourly factor).

Example A: Location: US 40 and Salisbury Road (Wayne County)

Date count was taken: Thursday, June 16, 1977

Time: first hour - 7:50-8:50 AM, second hour - 8:50-9:50 AM

Major road entering volume for first hour = 671

Major road entering volume for second hour = 780

Minor road entering volume for first hour = 90

Minor road entering volume for second hour = 86

Monthly factor = 1.118

Major road daily factor = .975

Minor road daily factor = 1.018

First hour hourly factor for major = .047

Second hour hourly factor for major = .051

First hour hourly factor for minor = .049

Second hour hourly factor for minor = .045

	<u>1st Hour</u>	<u>2nd Hour</u>
Major road ADT	$\frac{671}{1.118(.975).047} = 13097$	$\frac{780}{1.118(.975).051} = 14031$
	$\frac{13097+14031}{2} = \underline{13564}$	

Minor road ADT	$\frac{90}{1.118(1.018).049} = 1614$	$\frac{86}{1.118(1.018).045} = 1679$
	$\frac{1614+1679}{2} = \underline{1647}$	

Total intersectional ADT = 13564 + 1647 = 15211

Since data from recent 1977 volume counts conducted by the ISHC show little change since 1976 and since June 1977 was only six months away from 1976, these calculations using June 1977 volume counts were considered accurate enough to represent 1976 ADT's. The volumes also had to be factored to represent the 1974 and 1975 ADT's. This was done by calculating the change in volumes from permanent automatic traffic-recorders maintained by the ISHC on suburban, local and rural arterial roadways around the state (Table 1A). Factoring 1976 ADT to 1974 and 1975:

	1976	$\Delta\%$	Calculation	1975	$\Delta\%$	Calculation	1974
Major	13564	-5	$\frac{13564}{1.05} =$	12918	-.2	$\frac{12918}{1.002} =$	12892
Minor	1647	-3	$\frac{1647}{1.03} =$	1599	+.2	$1599(1.002) =$	1602
Total	15211	--	----	14517	--	----	14494

2. If the volumes were obtained from a traffic engineering study at the Traffic Division of ISHC, then usually a 12 Hour count was used and the year could have been between 1965 and 1977.

Example B: Location: US 30 and SR 5 (Whitley County).

Year of count: 1969

Factor for converting 12 hour count (6AM-6PM) to 24 hour count for state roads = .668

$$\text{US30: } \frac{3270}{.668} = 4895 \quad \text{SR5: } \frac{3360}{.668} = 5030 \quad \text{Total ADT} = 9925$$

The same procedure for factoring to the appropriate year was used as in Example A.

The AADT in Table 1A are the average for that year for all the stations which have been recording consistently since 1965.

Table 1A: AADT for Suburban, Local, and Highway Roadways in Indiana.

Year	Suburban	Local	Highway
1965	4599	883	8567
1966	4847	891	9138
1967	5047	878	9506
1968	5075	956	9815
1969	5369	1001	10277
1970	5921	1947	11116
1971	6742	1140	11853
1972	7288	1156	12938
1973	7631	1197	14099
1974	7746	1392	14000
1975	7864	1389	14029
1976	8140	1431	14715

Source: Division of Planning, ISHC, Chart "Variations of Traffic by Year as shown by Automatic Traffic Recorder Records".

APPENDIX B

INTERSECTION BY TRAFFIC CONTROL AND NUMBER OF ACCIDENTS

Table 1B: Intersections By Traffic Control and Number of Accidents.

	1975 Entering ADT		County	Total Accidents		ISHC LIST	
	Major	Minor		1974	1975		
INTERSECTIONS WITH FLASHERS							
US31 x SR38	13079	2825	Hamilton	11	22	13	X
US31 x SR14	3955	1659	Fulton	12	7	8	X
US31 x SR18	13837	2278	Miami	9	7	11	X
SR63 x SR163	3281	2244	Vermillion	4	7	11	X
SR37 x SR54/ 58	10283	1910	Lawrence	2	6	3	
US30 x SR5	3955	4064	Whitley	4	3	1	
US52 x Stockwell	4316	583	Tippecanoe	0	0	0	
SIGNALIZED INTERSECTIONS							
SR67 x Franklin	32412	15529	Marion	50	48	48	X
US31 x National	28125	2164	Marion	31	38	20	X
US31 x Kern	15401	3907	St. Joseph	32	30	25	X
SR37 x SR48	11958	11647	Monroe	27	32	24	X
US41 x 45th	24583	7760	Lake	23	31	26	X
SR67 x NB I465(NE)	35594	7154	Marion	31	32	13	X
SR37 x SR252	12647	4317	Morgan	18	24	22	X
SR67 x SB I465(SW)	19362	5452	Marion	21	17	22	X
SR67 x SB I465(NE)	29855	6064	Marion	22	23	14	X
US31 x SR28	12966	1069	Tipton	15	13	20	X
SR37 x SR450	10067	8211	Lawrence	3	34	11	X
US24 x Getz	16310	4865	Allen	20	12	21	
US31 x Morgan	22186	605	Howard	9	16	15	
US30 x SR9	10802	3924	Whitley	10	12	17	
US40 x Round Barn Rd.	13736	1634	Wayne	14	12	9	X
US30 x SR205	9328	2085	Whitley	13	8	12	
US40 x SR10	4199	1559	Newton	10	6	13	
SR67 x SR39(S.Jct.)	9221	8179	Morgan	6	10	11	X
US40 x SR1	6388	3909	Wayne	8	7	7	
US24 x SR5	6432	4833	Huntington	7	6	5	X

Table 1B. Continued

	1975 Entering ADT		County	Total Accidents			ISHC List
	Major	Minor		1974	1975	1976	
NONSIGNALIZED INTERSECTIONS							
SR67 x NB I465(SW)	19362	2533	Marion	16	9	17	X
US30 x Burr St.	21895	2267	Lake	7	11	15	X
US31 x E. Jefferson	25488	390	Howard	6	13	7	
Emerson x WB I465	16908	4200	Marion	4	12	9	X
US31 x Vaile	29009	1823	Howard	8	9	8	
Emerson x EB I465	14671	4192	Marion	3	8	8	X
US31 x SR47	16848	1233	Hamilton	3	2	7	
US40 x Salisbury	12796	1307	Wayne	6	2	2	
US30 x 300E	13445	715	Whitley	3	4	3	
US24 x SR114	7041	772	Whitley	2	5	0	
US24 x Meridian	9122	552	Huntington	0	5	1	
US31 x Smith	16382	1175	Howard	1	0	4	
US30 x 500E	12547	413	Whitley	2	0	3	
US52 x SR28	4121	627	Tippecanoe	2	2	0	
US30 x 600E	12566	593	Whitley	3	0	1	
SR37 x Rockport	7040	877	Monroe	0	3	1	
US52 x 350S	7514	720	Tippecanoe	0	2	1	
US41 x SR241	8696	332	Knox	0	2	0	
SR37 x 800N	10845	772	Morgan	2	0	0	
US30 x 900E	9215	167	Starke	1	0	1	
US40 x Meridian	14412	932	Hancock	1	0	0	
US30 x Hawthorn	7946	170	Marshall	0	1	0	
SR37 x Trogden	10189	374	Lawrence	1	0	0	
US41 x 1250S	14097	312	Gibson	0	1	0	
US52 x 550E	4171	252	Tippecanoe	0	0	0	
US52 x 830W	3420	122	Clinton	0	0	0	
US31 x 700N	13212	355	Tipton	0	0	0	
US41 x 7th St.	3375	308	Benton	0	0	0	
US30 x 800W	10366	22	LaPorte	0	0	0	

Table 1B Continued.

	1975 Entering ADT		County	1974	Total Accidents		ISHC List
	Major	Minor			1975	1976	
US30 x 100W	9087	48	LaPorte	0	0	0	
SR37 x 850E	11556	369	Morgan	0	0	0	
US41 x 850N	10505	371	Sullivan	0	0	0	
US41 x 1040N	10894	99	Sullivan	0	0	0	
US40 x Pleasant Gardens	4939	562	Putnam	0	0	0	

APPENDIX C

CALCULATION OF CONFLICT ADT

APPENDIX C: CALCULATION OF CONFLICT ADT

The calculation and development of a conflict ADT was originally devised by Walton, et. al. (49) to arrive at the probability of the occurrence of a conflict at a low-volume rural intersection. In this study, the procedure was modified to account for intersections of multi-lane highways and other roadways.

In Walton's analysis the following assumptions were made:

1. Conflict is defined as that maneuver of vehicle B (crossing vehicle) such that the driver of vehicle A (approaching main road vehicle) must change speed or direction to maintain a comfortable clearance interval.
2. Assumed average speed is 64 kph (40 mph) or approximately 18 mps (60 fps), and no intersection control or signing is provided.
3. Any two vehicles approaching the intersection from conflicting directions such that the second vehicle would enter the intersection within 3 seconds after the first vehicle enters the intersection are said to be in conflict, i.e., one or both vehicles must take a speed change maneuver to provide comfortable clearance.
4. Effects of right distance are not considered in the analysis portion.
5. All vehicles arrive during a 12-hour period from 7 am to 7 pm (this assumption covers the worst condition)
6. All arrivals are random that is, they follow a Poisson distribution.
7. Only one arrival per approach is possible during one three-second interval; i.e., all approaches are single lane and all headways are greater than three seconds.

8. The possibility of vehicles arriving on three approaches within a three-second interval is negated as the probability of such an occurrence is a maximum of 2.01×10^{-5} for the volumes under consideration.

For the present analysis the three-second conflict interval was changed to eight seconds based on a report by Wagner (47) which investigated the 50th percentile gap size that drivers will accept at a multi-lane highway intersection for the near-far situation. The near-far case is the one in which the driver on the minor road must choose a gap between a car approaching on the near lanes and another car approaching in the far lanes of the major road. In other words, if the gap is less than 8 seconds and the car on the minor road tries to cross the major facility, the possibility of a conflict will exist.

Other assumptions in this analysis which differ from Walton's were:

1. Even if there are 10 vehicles approaching on the major road from either direction and only one on the other in an eight second period (Δt), there can be only one conflict in that interval.
2. To give consideration for movement in both directions on the major and minor roads, the ADT volumes on these roads were used to compute the average rate of arrival for each road.

In theory, the probability that two vehicles will be in conflict is the product of the probability that either vehicle is in the conflict region during the interval Δt (8 sec.):

$$P(\text{conflict}) = P(\text{vehicle A in conflict region during } \Delta t) \times P(\text{vehicle B in conflict region during } \Delta t)$$

Of course, intersections of this type have some kind of traffic control, whether it be a stop sign, flasher, or a signal. And this fact is not accounted for in the assumptions, therefore the conflict ADT developed here is simply the possibility of conflict if no intersection control existed.

With the above assumptions the following calculations were carried out for each intersection:

1. Random arrival (Poisson distribution) of vehicles on the major and minor roads:

$$P(X) = \frac{(\lambda t)^X e^{-\lambda t}}{X!}$$

$P(X)$ = Probability that X vehicles will arrive during counting period of t

λ = average rate of arrival (vehicles/sec.)

t = duration of each counting period (sec.)

e = natural base of logarithms

Probability of more than zero vehicles approaching = $1 - P(0)$

$$2. \quad P(\text{conflict}) = [1 - P(0)_{\text{MAJOR}}] [1 - P(0)_{\text{MINOR}}] (\Delta t = 8 \text{ sec})$$

Expected number of conflicts in a Day =

$$E(C) = [1 - P(0)_{\text{MAJOR}}] [1 - P(0)_{\text{MINOR}}] \left[\frac{12(3600)}{8} \right]$$

$$3. \quad P(0) = \frac{(\lambda t)^0 e^{-\lambda t}}{0!} = e^{-\lambda t} \qquad \lambda t = \frac{\text{ADT}(8)}{12(3600)}$$

$$4. \quad E(C) = \left[1 - e^{-\frac{\text{ADT}_{\text{MAJOR}}(8)}{12(3600)}} \right] \left[1 - e^{-\frac{\text{ADT}_{\text{MINOR}}(8)}{12(3600)}} \right] \frac{12(3600)}{8}$$

Sample Calculation: US30 x Burr St. (Lake County)

1975 ADT

US30 21895

Burr St. 2267

$$E(C) = \left[1 - e^{-\frac{21895(8)}{12(3600)}} \right] \left[1 - e^{-\frac{2267(8)}{12(3600)}} \right] \frac{12(3600)}{8} = \underline{1819.2}$$

APPENDIX D

INTERSECTION TRANSFORMED ACCIDENT RATES

Table 1D: Intersection Transformed Accident Rates.

Site	Total Accidents	Conflict Rates		Rear-End Accidents	Volume Rate	
		Right-Angle Accidents	Right-Angle Accidents		Total Accidents	Accidents
52 x 350S	2.2	1.8	1.4	1.1	1.1	
52 x 550E	1.0	1.0	1.0	1.0	1.0	
52 x Stockwell	1.0	1.0	1.0	1.0	1.0	
52 x 28	3.2	2.1	1.0	1.3	1.3	
52 x 830W	1.0	1.0	1.0	1.0	1.0	
40 x Salisbury	3.0	2.2	1.5	1.3	1.3	
40 x Meridian	1.4	1.0	1.4	1.0	1.0	
67 x NB I465(NE)	4.2	2.4	3.2	1.9	1.9	
67 x SB I465(NE)	3.9	2.5	2.6	1.7	1.7	
31 x 700N	1.0	1.0	1.0	1.0	1.0	
31 x Vaile	4.0	3.4	1.8	1.3	1.3	
31 x Smith	2.1	1.7	1.3	1.1	1.1	
31 x 47	3.2	2.6	1.0	1.2	1.2	
41 x 7th	1.0	1.0	1.0	1.0	1.0	
30 x Burr	4.1	3.6	1.7	1.5	1.5	
30 x 800W	1.0	1.0	1.0	1.0	1.0	
30 x 100W	1.0	1.0	1.0	1.0	1.0	
30 x 900E	3.3	3.3	1.0	1.1	1.1	
30 x Hawthorn	2.2	2.2	1.0	1.0	1.0	
30 x 300E	3.9	3.9	1.0	1.3	1.3	

Table 1D Continued.

Site	Total Accidents	Conflict Rates <u>Right-Angle</u> Accidents	Rear-End Accidents	Volume Rate <u>Total</u> Accidents
30 x 600E	2.5	1.8	1.0	1.1
24 x Getz	4.1	3.2	2.4	1.8
24 x 114	3.2	3.2	1.0	1.3
24 x Meridian	3.1	3.1	1.0	1.2
31 x 18	3.9	3.3	1.6	1.6
37 x 800N	1.7	1.7	1.0	1.1
37 x 850E	1.0	1.0	1.0	1.0
37 x 252	4.7	3.7	2.2	2.1
41 x 850N	1.0	1.0	1.0	1.0
41 x 1040N	1.0	1.0	1.0	1.0
37 x Trogden	1.7	1.7	1.0	1.0
37 x 54/58	2.8	2.2	1.2	1.3
37 x Rockport	2.3	2.3	1.0	1.2
37 x 48	4.3	3.2	2.4	2.0
40 x Pleasant Gardens	1.0	1.0	1.0	1.0
41 x 1250S	1.8	1.0	1.0	1.0
41 x 241	2.2	1.8	1.0	1.1
41 x 10	5.9	5.4	2.6	2.3
67 x SB 1465(SW)	4.5	3.5	2.2	1.6
67 x SB 1465(SW)	4.1	2.8	2.4	1.8

Table 1D Continued.

Site	Total Accidents	Conflict Rates Right-Angle Accidents	Rear-End Accidents	Volume Rate Total Accidents
31 x Kern	5.6	3.5	4.1	2.3
41 x 45th	4.3	2.9	3.0	1.8
31 x 14	5.8	5.2	1.8	2.3
24 x 5	2.9	2.1	2.2	1.6
30 x 500E	3.1	2.9	1.5	1.1
30 x 5	2.4	2.1	1.0	1.4
30 x 9	3.9	2.5	2.7	1.8
30 x 205	4.6	2.2	2.7	1.9
63 x 163	5.4	4.7	2.4	2.3
31 x National	6.8	5.6	3.2	1.9
67 x Franklin	5.2	3.6	2.6	1.9
Emerson x 465 (EB)	2.7	1.5	1.8	1.4
Emerson x 465 (WB)	3.0	1.4	2.2	1.4
40 x 1	3.3	3.0	1.5	1.7
40 x Round Barn Road	5.0	4.3	2.4	1.7
31 x 38	4.1	2.9	2.0	1.4
31 x 28	7.0	3.5	5.4	2.0
31 x Jefferson	7.9	5.7	4.7	1.4
31 x Morgan	8.0	3.7	6.2	1.6
37 x 450	3.3	3.0	1.5	1.8
67 x 39	2.8	1.7	2.3	1.5

APPENDIX E

INTERSECTION DATA

Table 2E. Intersection Data

Intersection	Variable Number																									
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
US 52 x 350S	1	0	0	0	1	2	0	0	0	0	2	0	0	0	6	0	0	2	1	1	1	1	2	1	3	0
US 52 x 550E	0	1	0	0	1	2	0	0	0	0	2	0	0	0	4	3	0	2	0	0	0	2	1	2	0	0
US 52 x SR 28	0	1	0	0	1	2	1	0	0	0	4	0	0	0	6	2	0	2	1	1	0	0	2	0	0	0
US 52 x Stockwell	0	1	0	0	0	0	1	0	0	0	2	0	0	0	1	6	0	1	0	0	0	0	4	1	2	0
US 52 x 830W	0	1	0	0	1	2	0	0	0	0	2	0	0	0	5	3	1	2	0	0	0	0	2	1	2	0
US 40 x Salisbury Rd.	1	0	0	0	1	2	0	0	0	0	0	0	0	0	1	2	0	0	0	0	0	0	6	1	1	0
US 40 x Meridian Rd.	1	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	4	1	1	0
*SR 67 x NB I-465 (NE)	0	0	1	0	0	0	1	1	0	1	1	0	1	1	0	0	0	3	1	1	1	1	3	0	0	0
*SR 67 x SB I-465 (NE)	0	0	1	0	0	0	1	1	0	1	1	0	1	1	0	0	0	3	1	1	1	1	3	0	0	0
US 31 x 700N	0	1	0	0	1	2	0	0	0	0	5	1	0	1	0	2	0	2	0	0	0	0	2	1	4	0
US 31 x Vaile	0	1	0	0	1	2	0	0	0	0	3	1	0	3	3	3	0	3	1	0	0	0	2	1	3	1
US 31 x Smith	0	1	0	0	1	5	1	0	0	0	3	1	0	2	3	2	0	1	1	1	1	1	2	1	4	1
US 31 x SR 47	0	1	0	0	1	5	1	0	0	0	4	0	0	0	0	1	0	1	0	1	1	0	2	1	4	0
US 41 x 7th St.	0	1	0	0	1	2	1	0	0	0	4	0	0	0	1	3	4	0	1	1	0	0	1	1	5	0
US 30 x Burr St.	0	1	0	0	1	5	0	0	0	0	4	0	0	0	1	3	5	1	1	1	0	1	0	1	5	0
US 30 x 800W	0	1	0	0	1	5	0	0	0	0	4	0	0	0	1	0	1	0	2	0	0	0	2	0	0	0
US 30 x 100W	0	1	0	0	1	5	0	0	0	0	4	0	0	0	1	1	0	1	0	0	0	0	1	1	4	0
US 30 x 900E	0	1	0	0	1	5	0	0	0	0	4	0	0	0	1	1	0	0	1	0	0	0	1	0	0	0
US 30 x Hawthorn Rd.	0	1	0	0	1	3	0	0	0	0	4	0	0	0	2	3	2	0	2	0	0	0	1	1	4	0
US 30 x 300E	0	1	0	0	1	3	0	0	0	0	4	0	0	0	1	0	2	0	2	0	0	0	2	1	5	0
US 30 x 600E	0	1	0	0	1	2	0	0	0	0	4	0	0	0	2	2	3	0	1	1	1	0	3	1	5	0
US 24 x Getz Rd.	0	0	0	1	0	0	0	0	0	0	2	0	0	0	1	6	2	1	2	0	1	0	3	0	0	0
US 24 x SR 114	1	0	0	0	1	2	1	0	0	0	2	0	0	0	0	0	0	3	0	1	0	0	1	0	0	0
US 24 x Meridian	0	1	0	0	1	3	1	0	0	0	7	0	0	0	1	1	2	0	2	1	1	1	0	1	1	0
US 31 x SR 18	0	1	0	0	1	5	1	1	1	0	3	1	0	2	0	3	5	3	0	2	1	0	3	1	4	0
SR 37 x 800W	0	1	0	0	1	5	1	0	0	0	5	0	0	2	3	1	2	3	2	1	1	0	2	1	5	0
SR 37 x 850E	0	1	0	0	1	1	0	0	0	0	4	0	0	2	1	2	3	3	1	0	0	1	3	1	4	0
*SR 37 x SR 252	0	0	1	0	0	0	1	0	1	0	4	0	0	1	1	0	2	0	1	1	1	1	3	0	0	0
US 41 x 850N	0	1	0	0	1	3	0	0	0	0	6	0	0	0	1	0	3	0	2	0	0	0	1	1	5	0

Table 2E. Continued

Intersection	Variable Number																									
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
US 41 x 1040N	0	1	0	0	1	2	0	0	0	0	0	4	0	0	1	0	2	0	2	1	0	0	1	1	2	0
SR 37 x Troyden Rd.	0	1	0	0	1	2	1	0	0	0	5	0	0	1	0	4	1	2	0	0	0	0	1	1	5	0
SR 37 x SR 54/58	0	1	0	0	1	2	1	0	0	1	5	0	0	2	3	6	3	0	1	1	1	1	0	1	6	0
SR 37 x Rockport Rd.	0	1	0	0	1	2	0	0	0	0	4	1	0	1	2	4	0	1	0	0	1	0	1	1	4	0
*SR 37 x SR 48	0	0	1	0	0	0	0	1	1	0	4	0	1	2	0	4	0	2	1	1	1	1	3	0	0	0
US 40 x Pleasant Gardens Rd.	1	0	0	0	1	1	0	0	0	0	3	0	0	1	0	6	0	4	0	0	0	0	0	1	2	0
US 41 x 1250 S	0	1	0	0	1	2	0	0	0	1	4	0	0	1	0	0	0	2	1	1	0	1	4	1	5	0
US 41 x SR 241	0	1	0	0	1	3	0	1	0	1	5	1	0	2	6	2	3	2	1	0	0	1	2	0	0	0
US 41 x SR 10	0	0	0	1	0	0	1	0	0	1	4	0	0	1	3	2	0	1	1	1	1	1	5	0	0	0
*SR 67 x SB I-465 (SW)	0	0	1	0	0	0	1	1	0	1	3	0	0	1	0	2	0	1	1	1	0	1	2	0	0	0
SR 67 x NB I-465 (SW)	1	0	0	0	1	6	0	1	0	1	3	0	0	1	0	2	0	1	1	1	0	1	2	0	0	0
*US 31 x Kern Ave.	0	0	1	0	0	0	1	0	0	1	0	0	0	0	2	3	0	1	0	0	0	0	3	0	0	0
*US 41 x 45th St.	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	2	1	0	0	0	5	0	0	0
US 31 x SR 14	0	1	0	0	1	7	1	1	0	0	4	1	0	3	3	2	1	1	1	1	1	1	3	1	5	0
*US 24 x SR 5	0	0	1	0	0	0	0	1	0	0	3	0	1	1	0	2	0	2	1	1	0	1	5	0	0	0
US 30 x 500E	0	1	0	0	1	2	1	0	0	0	4	0	0	1	3	3	0	1	1	1	0	1	4	1	4	0
US 30 x SR 5	0	1	0	0	1	2	0	1	0	0	4	1	0	2	0	2	0	1	1	1	1	1	2	1	5	0
US 30 x SR 9	0	0	1	0	0	0	1	0	0	0	4	0	1	2	3	3	0	1	1	1	0	1	5	0	0	0
US 30 x SR 205	0	0	1	0	0	0	1	1	0	1	5	0	1	2	1	1	0	1	1	1	0	0	2	0	0	0
SR 63 x SR 163	0	1	0	0	1	6	1	1	0	0	4	1	0	2	0	0	0	2	1	1	0	1	2	1	5	0
*US 31 x National Ave.	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	2	1	1	0	0	0	0	4	0	0	0
*SR 67 x Franklin Ave.	0	0	1	0	0	0	0	1	0	0	0	0	1	0	6	3	0	2	1	0	0	0	6	0	0	0
Emerson Ave. x EB I-465	1	0	0	0	1	6	0	1	0	0	1	1	0	0	3	2	0	0	1	1	1	0	4	0	0	0
Emerson Ave. x WB I-465	1	0	0	0	1	6	0	1	0	0	1	1	0	0	2	2	0	0	1	1	1	0	3	0	0	0
US 40 x SR 1	0	0	1	0	0	0	1	1	0	1	1	0	1	0	0	3	0	2	1	0	0	0	6	0	0	0
*US 40 x Round Barn Rd.	0	0	1	0	0	0	1	1	0	1	1	0	0	0	0	0	0	2	0	0	0	0	2	0	0	0
US 31 x SR 38	0	1	0	0	1	5	1	1	0	0	4	1	0	1	6	0	0	0	1	1	0	0	3	1	4	0
*US 31 x SR 28	0	0	1	0	0	0	1	1	0	1	4	0	0	1	0	3	0	1	1	1	0	0	4	0	0	0
US 31 x E. Jefferson St.	0	1	0	0	1	2	1	0	0	0	3	1	0	1	0	2	0	1	1	1	1	1	2	1	4	1

Table 2E. Continued

Intersection	Variable Number																									
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
US 31 x Morgan Ave.	0	0	1	0	0	0	1	0	0	0	3	0	1	1	4	3	0	3	1	0	0	0	2	0	0	1
*SR 37 x SR 450	0	0	1	0	0	0	1	1	1	0	5	0	1	2	1	5	0	2	1	1	1	0	2	0	0	0
*SR 67 x SR 39 (N. Jct.)	0	0	1	0	0	0	1	1	1	0	4	0	1	1	0	0	0	2	0	1	1	1	3	0	0	0

*The 14 signalized high accident intersections provided by ISHC. As some actuated signals were actually operated as fixed time signals for considerable time during the accident period, these intersections were all coded as fixed time signals and analysis of them was treated as if they were signalized without regard to actuated or fixed time.

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