An Analysis of Traffic Accidents on a High-Volume Highway

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INTRODUCTION

In the United States (1)* and in Indiana (12) the population, the number of vehicle miles, the number of motor vehicle registrations, and the number of deaths from traffic accidents, 1953 to 1963, increased as shown in Figures 1 and 2. However, the death rate per 100 million vehicle miles decreased substantially during this ten year period. Although successful steps have been taken to reduce motor vehicle accidents, the highway engineer is the first to admit that there is room for much improvement. The Joint Highway Research Project in 1964 initiated a traffic engineering demonstration project on the U. S. 52 Bypass at Lafayette-West Lafayette, Indiana. One of the first phases of this study was a study in depth of the traffic accidents which occurred on this facility to develop recommendations for traffic engineering improvements which would reduce accidents on this facility and information of value on other high volume urban highways.

The Lafayette-West Lafayette Bypass was the scene of 834 accidents between January 1, 1961, and December 31, 1963. A total of 374 injuries and ten deaths resulted from these accidents. These are the accidents which were investigated in this study.

THE STUDY LOCATION

The combined population of Lafayette and West Lafayette is approximately 55,000. This does not include approximately 15,000 of the Purdue University students who live outside the city limits.

Traffic using this facility is through, terminal or local in nature.

* The numbers in parentheses refer to numbers in the bibliography.

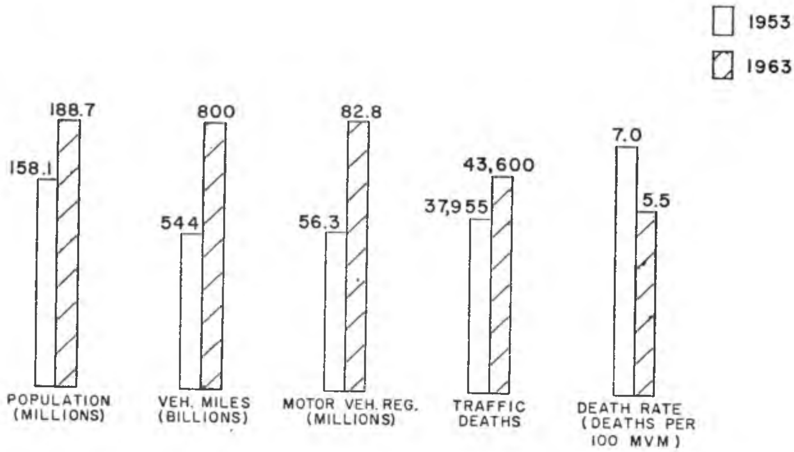

Fig. 1. Populations, vehicle miles, motor vehicle registration, traffic deaths and traffic death rates for the United States in 1953 and 1963.

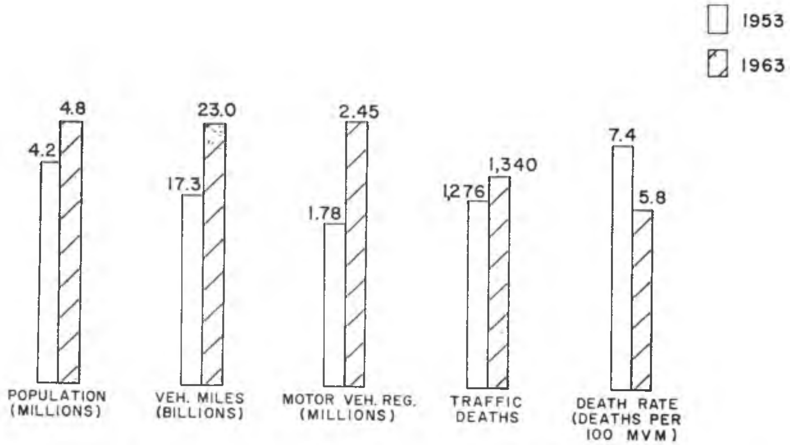

Fig. 2. Population, vehicle miles, motor vehicle registration, traffic deaths and traffic death rates for Indiana in 1953 and 1963.

Since the bypass is on a direct route between Chicago and Indianapolis, commercial vehicles represent approximately fourteen percent of daylight traffic and a much higher percentage during hours of darkness. Through trips constitute less than fifty percent of the travel.

A large percentage of the traffic terminates in Lafayette, an industrial center and the county seat of Tippecanoe County, or in West Lafayette at Purdue University. A portion of the traffic is local, seeking access to commercial and industrial establishments located on the bypass.

The bypass was constructed in 1938 in a rural area around the two cities. Since then development has occurred on both sides of the facility until much of the bypass is an urban arterial.

The location of the U.S. 52 Bypass in relation to the two cities

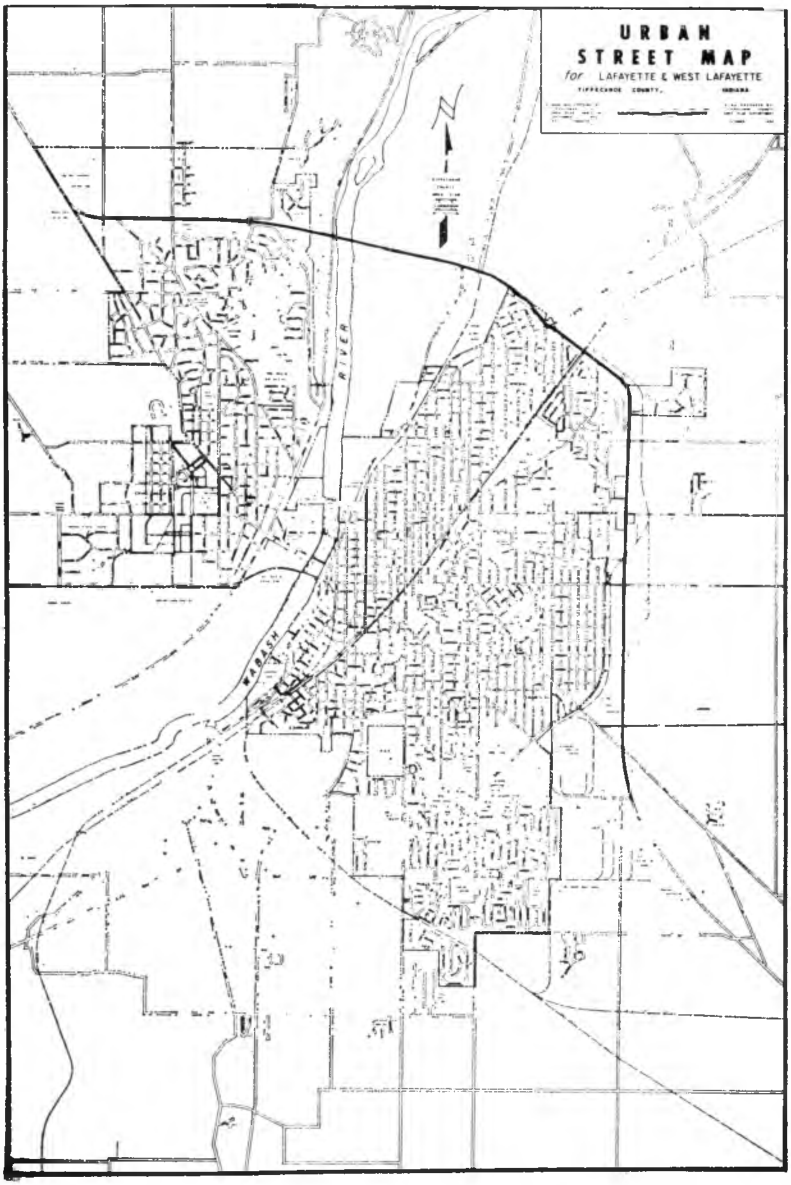

Fig. 3. Map of Lafayette and West Lafayette, Indiana.

is shown in Figure 3. A portion of the facility with illustration of the growth of the extensive development along it is shown in Figure 4.

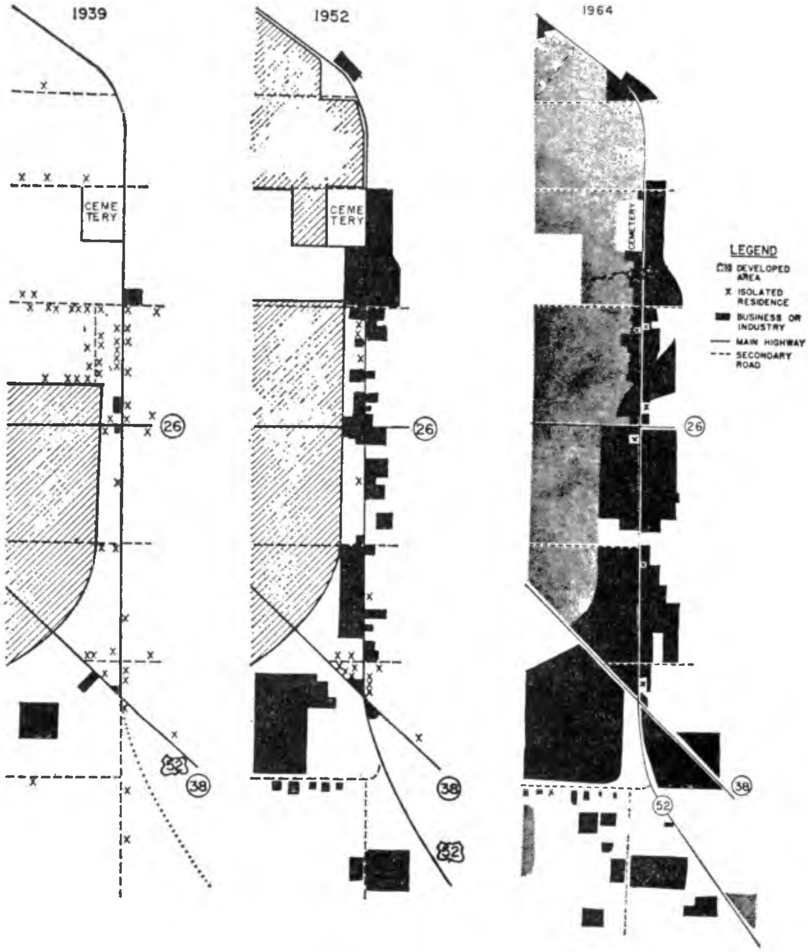

Fig. 4. Development along portion of the U. S. 52 Bypass for 1939, 1952 and 1964.

STUDY PROCEDURE

Accident Data

A three year study period was chosen in order that an adequate sample of accidents could be obtained. The last three years of accident data available were 1961-1963. Therefore, the study dates were chosen to include the period of January 1, 1961 through December 31, 1963.

Most of the accident data were collected from the Accident Records Division of the Indiana State Police. Indiana State law requires that all accidents involving a personal injury, death or property damage of $50 or more be reported to the police. Some of the accident information was obtained from the files of the Lafayette police, West Lafayette police and Indiana State Police Post No. 3 at Lafayette.

The accident information reported on the investigating officer's accident report form was available from the Accident Records Division in coded form. The punch cards for the accidents on U.S. 52 in Fairfield and Wabash Townships were obtained. The increasing annual number of these accidents is shown in Figure 5.

Information which was desired but which was not on the punch cards as obtained included whether the vehicle was turning right or left, the direction of travel before the accident, the exact location of the accident and the addresses of the drivers. This information was

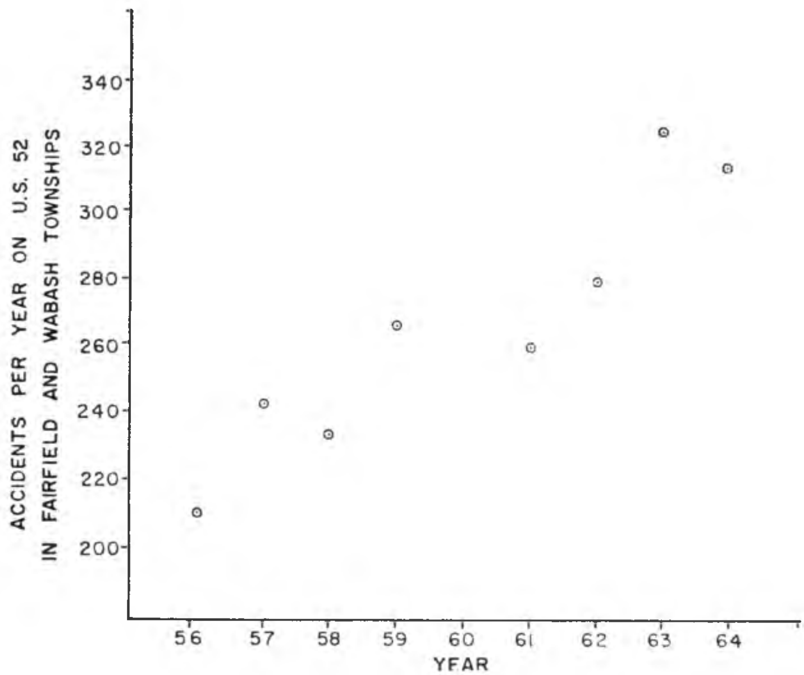

Fig. 5. Annual number of accidents on U. S. 52 in Fairfield and Wabash Townships from 1956-1964.

obtained from the original accident reports and placed on the same punch card along with the previously coded information. By use of the detailed location on the original accident report, the bypass accidents were separated from the other accidents occurring on U.S. 52 in Fairfield and Wabash Townships.

Preliminary study indicated that of all accidents approximately 56.7 percent happened within 100 feet of an intersection while about 65.1 percent happened within 200 feet of an intersection (see Figure 6). An additional 300 feet gave an increase of only 10 percent and at a distance greater than 200 feet most of the accidents were influenced by factors other than intersection characteristics. Therefore, all accidents which happened within 200 feet of each intersection on the cross streets were included in the study, and accidents within 200 feet

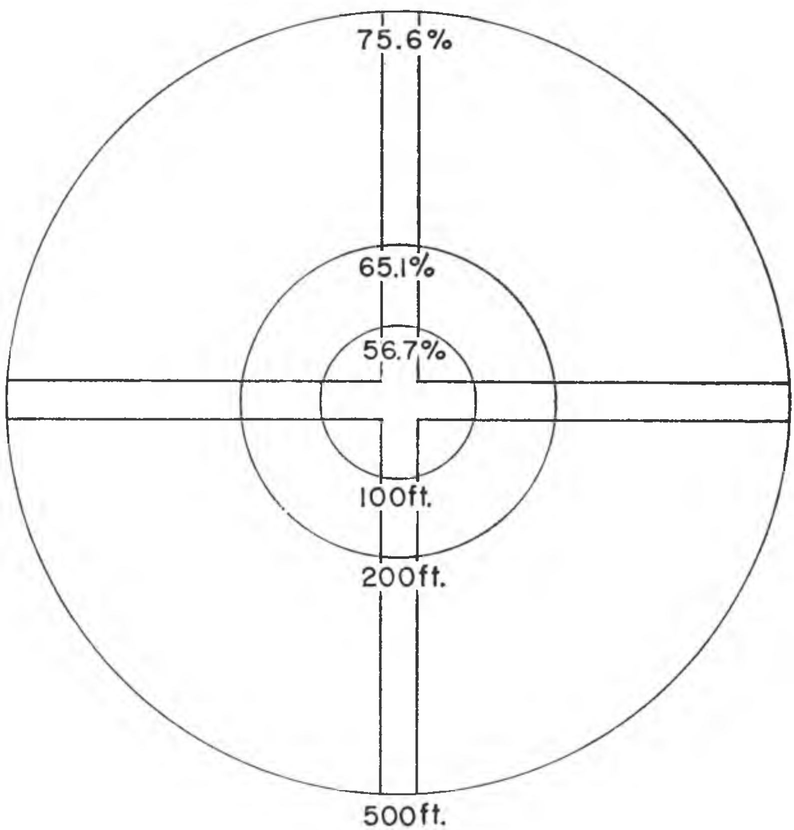

Fig. 6. Percentage of all accidents that happened within 100, 200 or 500 feet of an intersection.

of each intersection on the bypass and the cross streets were analyzed as intersection accidents. Data on accidents occurring on the cross streets within 200 feet of the bypass were obtained from local police records and coded in the same manner as the U.S. 52 bypass accidents.

A collision diagram was drawn for each accident.

Highway Elements

The bypass study section extended from the northwest corner of West Lafayette to the southeast corner of Lafayette. With the aid of aerial photographs and field inspection the bypass was divided into sections. Each section was selected so that it would have similar physical characteristics, commercial development, and volume of traffic throughout its length.

Fourteen intersections were considered to have a large enough cross street volume to warrant consideration as an intersection study section. A few other intersections with low cross street volumes (below 500 ADT) were considered within the section in which they occurred. By these criteria, the bypass was divided into twenty-four nonintersection sections and fourteen intersection study sections. These sections are illustrated in Figure 7.

An inventory of the physical features of each section was conducted in the summer of 1964. Many highway characteristics (variables) which might affect accident rates were considered in the analysis of each section. Physical conditions that changed during the three year period were determined by consulting the Traffic Division of the Crawfordsville District, Indiana State Highway Commission. Annual Lafayette-West Lafayette City Directories were used to determine the year each commercial establishment was developed along the bypass.

Volume

In many accident studies volume has correlated well with accidents. Volume has been usually represented by annual average daily traffic (ADT). In this study the hourly volume at the time of the accident as well as the ADT was correlated with accident occurrence. Because hourly volume counts were not taken during all of the 1961-1963 period, these volumes were estimated as indicated in the following paragraphs.

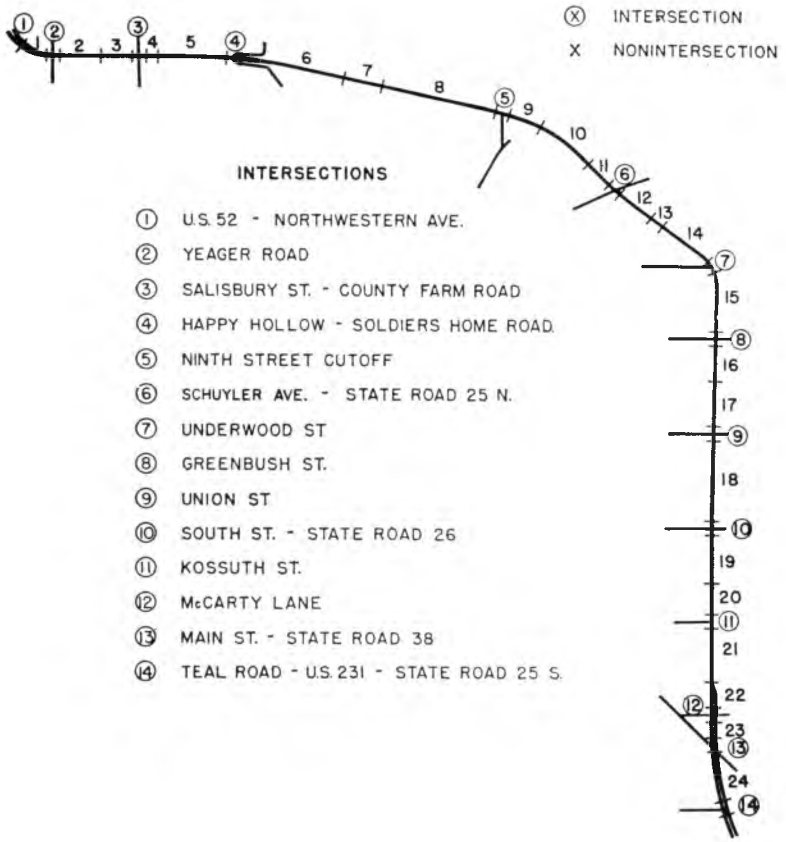

Fig. 7. U. S. 52 Bypass study sections.

Traffic counts taken during the summer of 1964 were supplemented by volume data from the Division of Planning, Indiana State Highway Commission (see Figure 8 for ADT volume growth at one point on the bypass). Factors were determined from the count data on the bypass and from records of the Highway Commission for yearly, monthly, daily, and hourly variations in traffic volume for each study section. Therefore, by knowing the location, year, month, day, and hour of an accident, the hourly volume was estimated by applying the appropriate factors to volume counts taken on or near each section during the study.

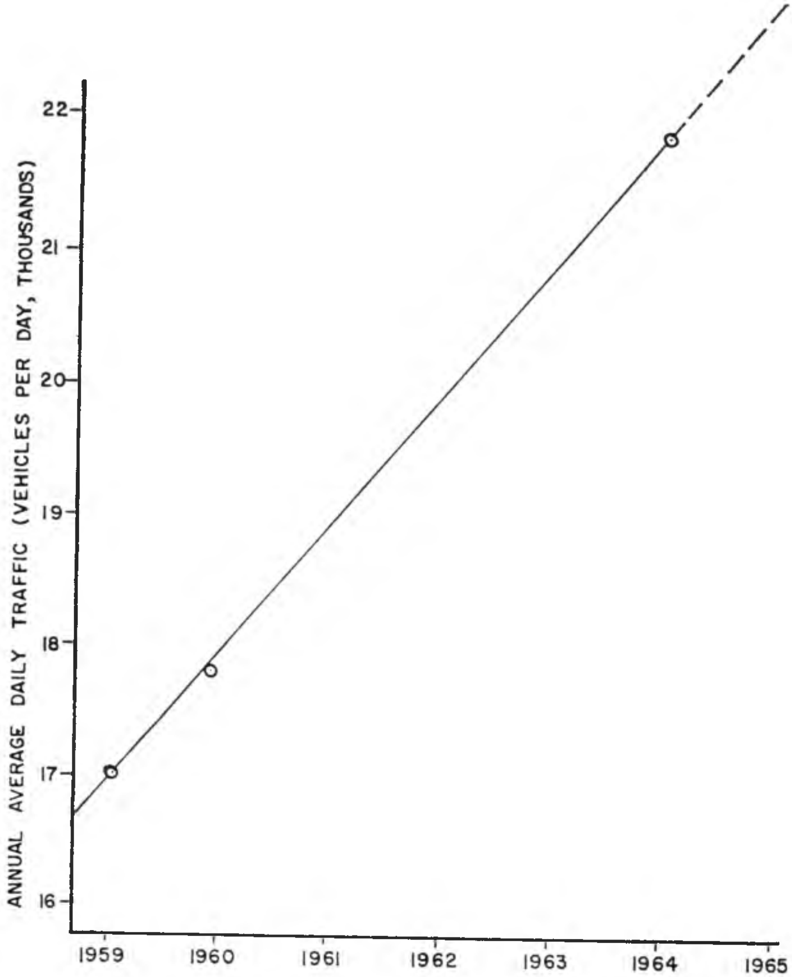

Fig. 8. Annual average daily traffic on U. S. 52 Bypass south of S.R. 26.

Figure 9 illustrates the 1963 ADT volume on the bypass and the cross streets.

Capacity

The practical capacity for each nonintersection study section was calculated by the method described in the *Highway Capacity Manual* (5).

In order to determine the practical capacities of the signalized intersections a study was made to determine the effect of paved shoulders near intersections on the practical capacity. Possible capacities were obtained for each approach to the intersection by counting the number

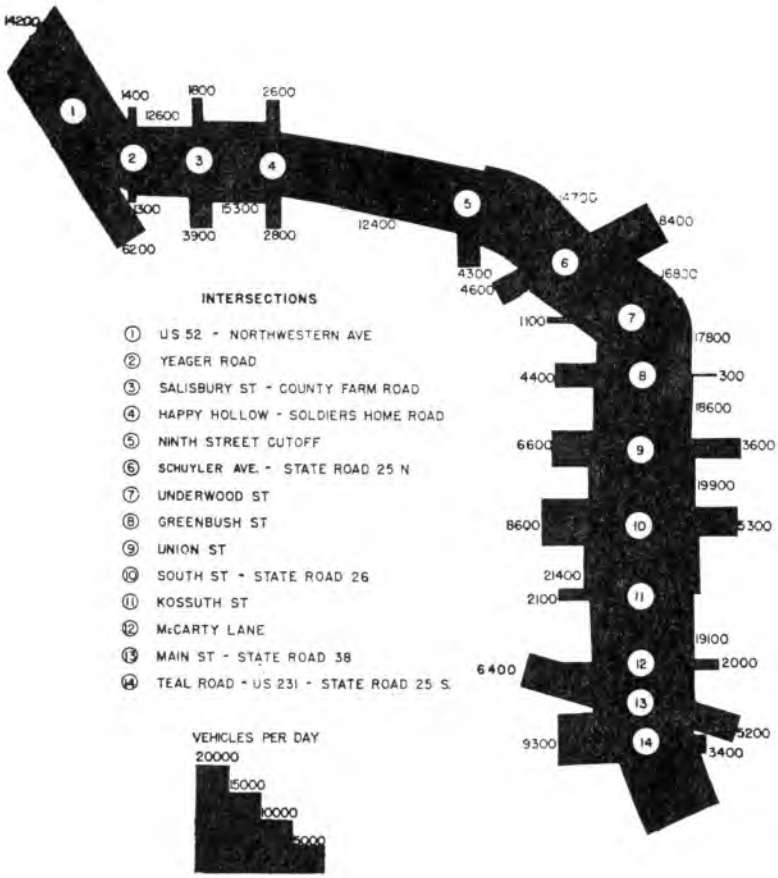

Fig. 9. 1963 ADT volume on the U. S. 52 Bypass and cross streets.

of vehicles which entered from that approach per loaded cycle. A loaded cycle was one that always had one or more vehicles waiting to proceed through the intersection. These counts were then converted to a volume per hour of green time. The counts were then adjusted by appropriate factors from the *Highway Capacity Manual* for practical capacity, left and right turns, commercial vehicles, parking, and bus stops. This study indicated that a paved shoulder near the intersection carried approximately one-third the capacity of a properly constructed and signed turning lane.

The practical capacity for each signalized intersection was computed using the revised curves for the *Highway Capacity Manual* (10) for one eleven-foot through lane in each direction. Then the practical capacity was calculated for an extra turning lane if the shoulder was paved near the intersection or if a turning lane existed. This lane was assumed to be a left-turn-only lane if the predominant turning movement at that approach was left and assumed to be a right-turn-only if the predominant turning movement at that approach was right. If the additional lane was only a paved shoulder, only one-third of the turning-lane capacity was added to the through-lane capacity. The practical capacities were thus determined for the conditions that existed at each signalized intersection.

The possible capacity for nonsignalized intersections was calculated in the following manner. The headway distribution on the bypass was assumed to be as that shown on page 40 of the *Highway Capacity Manual.* The average acceptable gap at stop-controlled intersections was considered as eight seconds (18). Each succeeding vehicle was assumed to require an additional four seconds to move to the next position in the queue and stop (13). Based on these assumptions, for any given hourly volume on the bypass, an approach capacity was determined for the minor street. This relationship between hourly volume in the major direction on the bypass and hourly capacity on the minor street approach is shown in Figure 10.

ANALYSES OF DATA

The data for the many variables were analyzed by multiple linear regression and the technique of quality control was also applied to each section. Accident rates were calculated for each section and collision condition diagrams were prepared for each accident.

Multiple Linear Regression

The multiple linear regression method was utilized to provide a generalized analysis of the factors associated with accidents at intersections and sections of the highway and to provide an expression for predicting accidents at each such location.

All of many variables which come to mind and could be measured were used in the preliminary analysis for intersections. These results were examined and certain variables were deleted. Some of the deleted variables had very small simple correlations with the dependent variable. Some variables had a very high intercorrelation coefficient. In such cases one of the variables was deleted from further calculations. Table 1 contains the variables that remained for the final analysis.

Prediction equations were then obtained for each of several dependent variables. The equation for the most popular accident rate

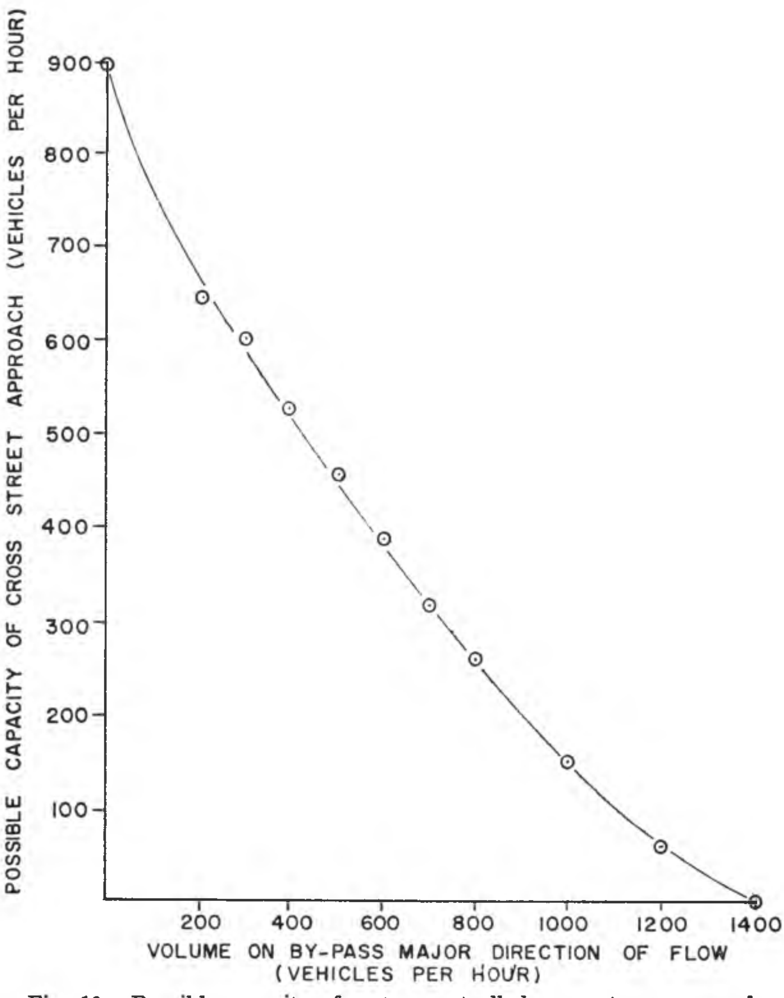

Fig. 10. Possible capacity of a stop-controlled cross street approach for major direction hourly volumes on the Bypass.

at intersections, number of accidents per 100 million vehicles (Y_{28}), was found to be:

$$Y_{28} = -309.860 - 0.908X_2 + 0.014X_3 + 0.025X_4 + 4.868X_{11} + 4.832X_{13} + 10.585X_{15} - 0.154X_{21}$$

The multiple correlation coefficient of the above was 0.873. The variables explain approximately 76 percent (r^2) of the variation in intersection accident rates.

Important variables in estimating this accident rate at intersections are the percentage of green time allotted to the bypass (100 percent

Table 1. Independent Variables Used in Final Multiple Linear Regression Analysis

INTERSECTIONS	
Variable Number	Description
2	Percent green time on bypass, percent
3	Bypass ADT, vehicles per day
4	Cross street ADT, vehicles per day
5	Total ADT, vehicles per day
11	Maximum percent left turns from a bypass approach, percent
12	Maximum percent left turns from a cross street approach, percent
13	Maximum approach speed, mph
15	Total number of establishments within 200 feet of intersection
16	Total number of driveways within 200 feet of intersection
19	Number of approaches to intersection
21	Total width of driveways, feet, within 200 feet of intersection
22	Maximum percent right turns from bypass, percent
23	Maximum percent right turns from cross street, percent
25	Distance from extremities of bypass, feet

green time meant there was no traffic signal present) (X_2), the bypass daily traffic (X_3), the cross-street daily volume (X_4), the percent of left turns from the bypass (X_{11}), the maximum approach speed to the intersection (X_{13}), the number of establishments within 200 feet of the intersection (X_{15}), and the total width of driveways within 200 feet of the intersection (X_{21}).

The variables for nonintersections listed in Table 2 are those remaining after other less significant variables were removed as in the intersection analysis.

The important variables found for the prediction equation for Y_{29}, accidents per 100 million vehicle miles, were total establishments per mile (X_3), the percent of no-passing distance (X_{15}), the number of intersections adjacent to the study section (X_{18}), the geometric modulus (17) (X_{19}), the total width of driveways per mile (X_{25}) and the distance from the extremities of the bypass (X_{26}). These variables had a multiple correlation coefficient of 0.574 and explained approximately 33 percent of the variation in nonintersection accident rates. This percentage is considerably less than that found for intersections.

The equation found for Y_{29}, accidents per 100 million vehicle miles for the nonintersection sections, was:

$$Y_{29} = -876.300 + 15.678X_3 + 1.319X_{15} - 13.979X_{18} + 20.307 X_{19} - 0.133X_{25} + 0.010X_{26}$$

Table 2. Independent Variables Used In Final Multiple Linear Regression Analysis

NONINTERSECTIONS

Variable Number	Description
3	Total number of establishments per mile
6	Total number of driveways per mile
9	Total shoulder width, feet
12	Total number of low volume intersections per mile
15	Percentage no-passing distance
18	Number of intersections adjacent to section
19	Geometric modulus
20	Practical capacity, vehicles per hour
21	ADT, vehicles per day
24	Operating speed, mph
25	Total width of driveways per mile, feet
26	Distance from extremities of bypass, feet
28	Length of turning lanes in section, feet
56	ADT per practical capacity

Quality Control

Quality control analysis of highway accidents has been used in several studies. (Norden, Orlansky, and Jacobs, 1956 and Blindauer, 1958). The method is useful in determining sections of highway that have a much higher accident rate because of some factor or factors unique to those sections.

In applying the quality control method of analysis to highway accident data, the following expressions were used:

$n_i = (ADT)(365)(10^{-6})$ for intersections

$n_i = (ADT)(365)(L)(10^{-6})$ for nonintersection sections

$$p_i = \frac{a_i}{n_i}$$

$$\bar{p} = \frac{a_i}{n_i}$$

$$s_i = \frac{p(1-\bar{p})}{n_i} \quad \text{or} \quad \frac{p}{n_i}$$

$$CL_i = \bar{p} \pm 3s_i$$

where

i = The number of the section considered

n_i = The number of million vehicles passing through an intersection or the number of million vehicle miles in a section

a_i = The number of accidents per year in a section

$\bar{p}$ = The over-all accident rate for a group of intersections or sections,

s_i = The estimate of the standard deviation for an intersection or section,

CL_i = The upper or lower control limit for p_i on any intersection or section,

L = Length of section in miles,

ADT = Annual average daily traffic volume.

The expression for (1-p) was eliminated from the expression for s_i since (1-p) very nearly approaches unity.

The bypass sections were divided into three classifications: signalized intersections, nonsignalized intersections, and nonintersection sections. For each of these groups an average accident rate, p, was calculated for the three-year period. For each section p_i, n_i, a_i, s_i, UCL_i, and LCL_i were calculated and plotted. In this manner any section that was out of control was detected by visual inspection of the control chart. A section out of control was one in which the accident rate was above or below a control limit. When a section fell out of the confidence bands, it was assumed that there was an assignable cause or causes that explained the high accident rate.

Examples of these control charts showing intersections or sections out of control are in Figures 11 and 12. These intersections or sections

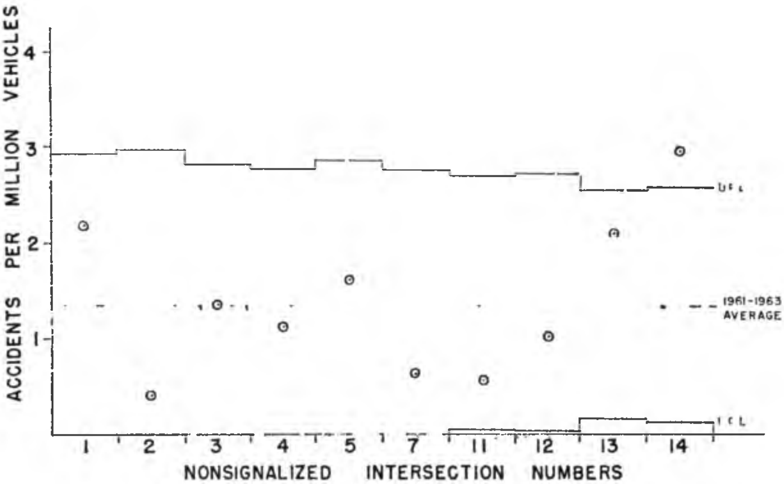

Fig. 11. Quality control chart for nonsignalized intersection, 1962.

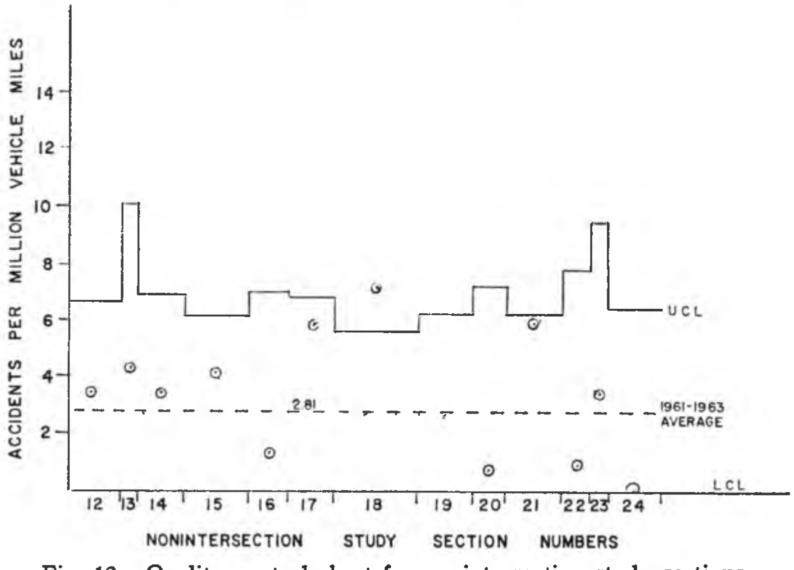

Fig. 12. Quality control chart for nonintersection study sections, 12-24, 1963.

were also analyzed further by use of collision-condition diagrams and field observations.

Accident Rates

Since the number of accidents per million vehicles was highly correlated with intersection ADT (correlation coefficient of 0.610), volume was used as an exposure index in order to provide a more realistic basis for comparing different intersections. These accident rates were computed in the following manner:

$$\text{Accident rate} = \frac{\text{Number of accidents per year at the intersection}}{\text{Number of vehicles going through the intersection per year from all approaches (in millions)}}$$

Accident rates for the bypass intersections are shown on Figure 13. The rate is number of accidents per one million vehicles.

The accidents per MV and the relative rankings of the intersections by this method are shown in Table 3.

A commonly used rate for accidents is accidents per million vehicle miles and this rate was used for evaluating the relative hazard of each of the nonintersection sections. The rate for each such section

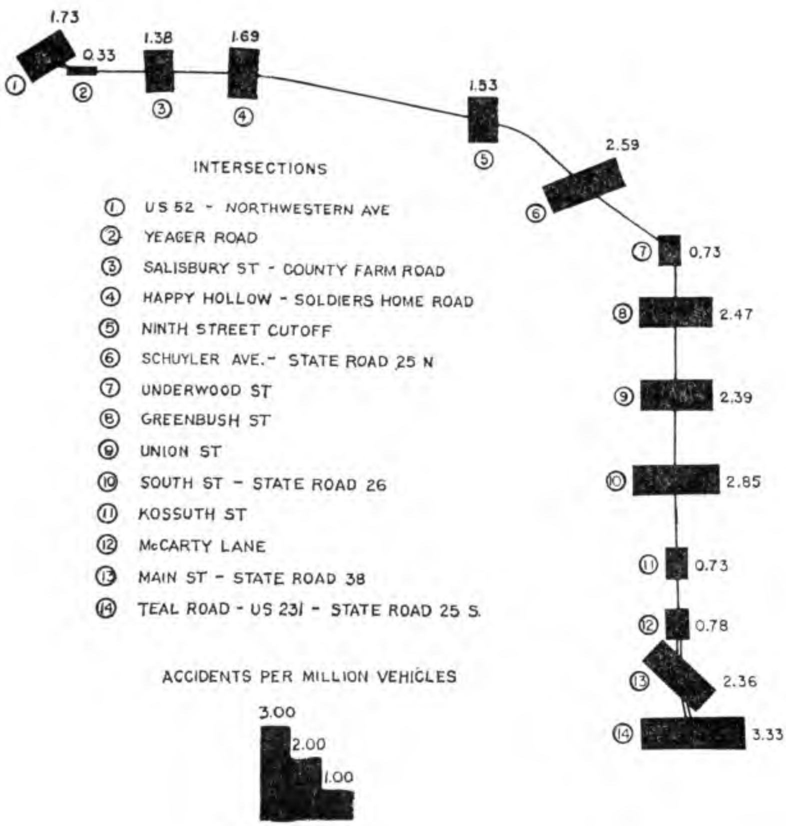

Fig. 13. Average annual intersection accident rate for 1961, 1962 and 1963.

Table 3. Ranking Of Intersections By Average Number Of Accidents Per Million Vehicles, 1961-1963

Rank	Intersection	Accident Rate
1	Teal Road	3.33
2	State Road 26	2.85
3	State Road 25	2.59
4	Greenbush	2.47
5	Union	2.39
6	State Road 38	2.36
7	Northwestern	1.73
8	Happy Hollow	1.69
9	Ninth St. Cutoff	1.53
10	Salisbury	1.38
11	McCarty	.78
12	Underwood	.73
13	Kossuth	.73
14	Yeager	.33

of the bypass is shown on Figure 14 and the relative ranking of these sections by this hazard rate is shown in Table 4.

Collision-Condition Diagrams

Each intersection was also analyzed for each of the three years by using the familiar collision-condition diagrams. The results of such analysis for three of the intersections follow:

1. S. R. 25 North and Bypass

   This is the third most hazardous intersection. Nearly one-third (18) of the accidents resulted from improper lane usage. These accidents often resulted from vehicles trying to change traffic lanes at the last minute. Ten of these accidents happened in approach lanes and eight in exit lanes. There were nine right angle collisions indicating some involved vehicles possibly were going through on the red. Of the 13 rear-end collisions on the bypass approaches, nine involved southeast bound vehicles. In the three-year study period, vehicles turning left from the

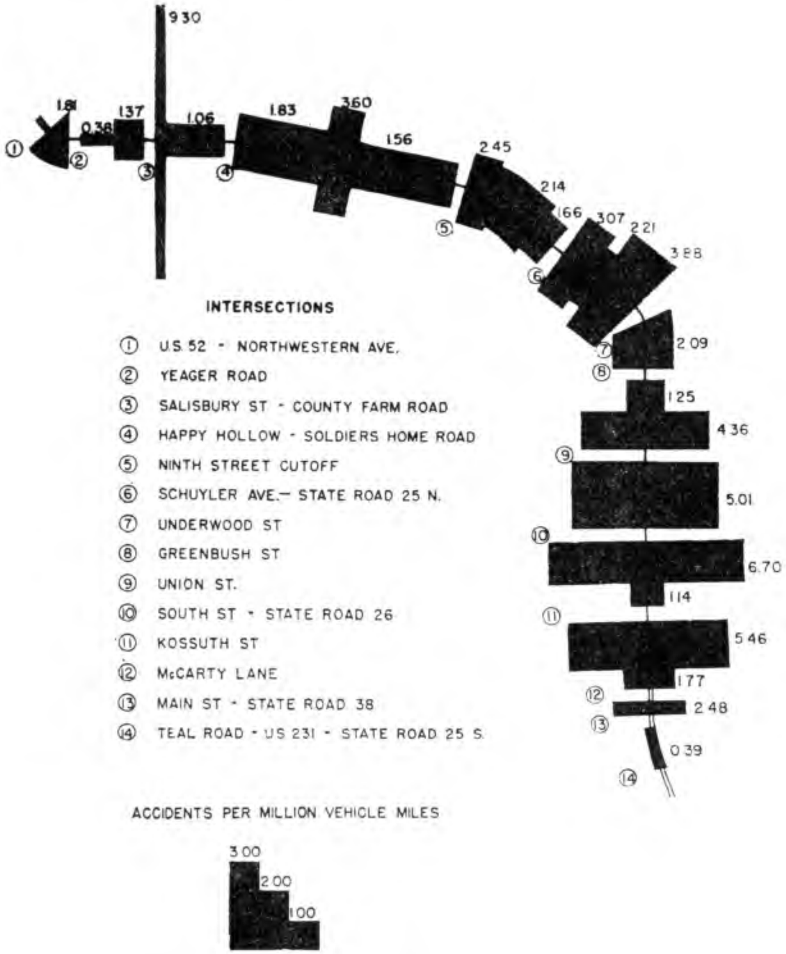

Fig. 14. Average nonintersection accident rates on the U. S. 52 Bypass for 1961, 1962 and 1963.

bypass were involved in only two accidents, both occurring in 1961.

2. S.R. 26 and Bypass
   This is the second most hazardous intersection and has the highest intersection ADT.
   The types of accidents are summarized below.

Types of Accidents at State Road 26

	1961	1962	1963
Total accidents	27	24	30
Injury accidents	2	3	6
Right angle	2	0	2

Left turn	6	8	10
Rear-end	18	16	15
Lane change	2	2	5
North bound vehicles	21	10	18
South bound vehicles	20	25	29
East bound vehicles	4	7	4
West bound vehicles	8	6	4

At this intersection south bound vehicles had more accidents than north bound traffic. The opposite is true for the bypass as a whole.

Table 4. Ranking Of Nonintersection Sections By Average Number Of Accidents Per Million Miles

Rank	Sect. No.	Acc. MVM
1	4	9.30
2	19	6.70
3	21	5.46
4	18	5.01
5	17	4.36
6	14	3.88
7	7	3.60
8	12	3.07
9	23	2.48
10	9	2.45
11	13	2.21
12	10	2.14
13	15	2.09
14	6	1.83
15	1	1.81
16	22	1.77
17	11	1.66
18	8	1.56
19	3	1.37
20	16	1.25
21	20	1.14
22	5	1.06
23	24	0.39
24	2	0.38

3. Teal Road (U.S. 231)

The accident rate indicated that this was the most hazardous of the bypass intersections. Quality control charts also showed that this intersection was out of control each of the three years.

The different types of accidents that occurred prior to the installation of the traffic signal in January 1963 and after this change are shown below.

Types of Accidents Before and After Traffic Signal Installation

	Before	After	Ratio$(\frac{\text{After}}{\text{Before}})$*
Total accidents	44	38	1.7
Time in months	24	12	1.0
Injury accidents	10	15	3.0
Right angle	29	15	1.0
Left turn	10	4	0.8
Rear-end	4	17	8.5
Lane change	1	4	8.0
North bound vehicles	16	34	4.3
South bound vehicles	21	27	2.6
East bound vehicles	32	17	1.1
West bound vehicles	**	8	——

* With all ratios adjusted to make time in months equal one.

** No west bound approach prior to signal.

All types of accidents increased with one exception, left-turn accidents. Left-turn lanes were constructed on the bypass when the signal was installed.

Each nonintersection accident was analyzed by use of the collision diagrams drawn from the investigating officer's report. A summary of the results of this analysis is shown in Table 5. This table presents the sections rated as the most hazardous. These ten sections had 74 percent of the nonintersection accidents.

Section 4 had a large percentage of injury accidents. Seven of the eight accidents were marginal accidents and six of the eight accidents occurred during a high-volume hour of the day.

On section 7, the Wabash River Bridge, six of the nine accidents occurred when the pavement was wet or icy.

Seven of the eleven accidents on section 10 happened at night. Six of the total accidents were on wet or icy pavement.

Table 5. Types of Accidents on the Most Hazardous Nonintersection Study Sections

	Section Number											
	4	7	10	12	14	15	17	18	19	21	Total	% of these acc.
Accident Rate	9.30	3.60	2.14	3.07	3.88	2.09	4.36	5.01	6.60	5.46	4.29	—
No. of Acc.	8	9	11	15	16	13	19	45	40	31	207	—
Injuries	7	6	3	5	10	12	14	18	28	12	115	—
Pavement wet or icy	4	6	6	6	5	6	3	12	16	18	82	40
Type I	0	0	1	1	0	2	6	15	9	2	36	18
Type II	7	1	2	5	8	7	8	23	26	21	108	52
Type III	1	3	4	3	7	1	2	2	3	1	27	13
Type IV	0	5	4	6	1	3	3	5	2	7	36	17
7-8 AM 2-8 PM	6	4	3	6	12	6	14	31	25	19	126	61
Night	1	3	7	6	1	0	1	4	4	6	33	16

On section 12, six accidents happened during the peak hours and six occurred at night. One-half of the accidents on section 14 involved vehicles trying to enter the traffic stream at an access point. Three-fourths of the accidents occurred during the peak hours. Section 15 had a high percentage of injury accidents.

One half of the nonintersection accidents occurred on sections 17 thru 21. On this 1.6 miles of highway, 58 percent of the accidents involved marginal friction, two-thirds of the accidents occurred during the peak hours, and 35 percent of the accidents occurred when the pavement was wet or icy.

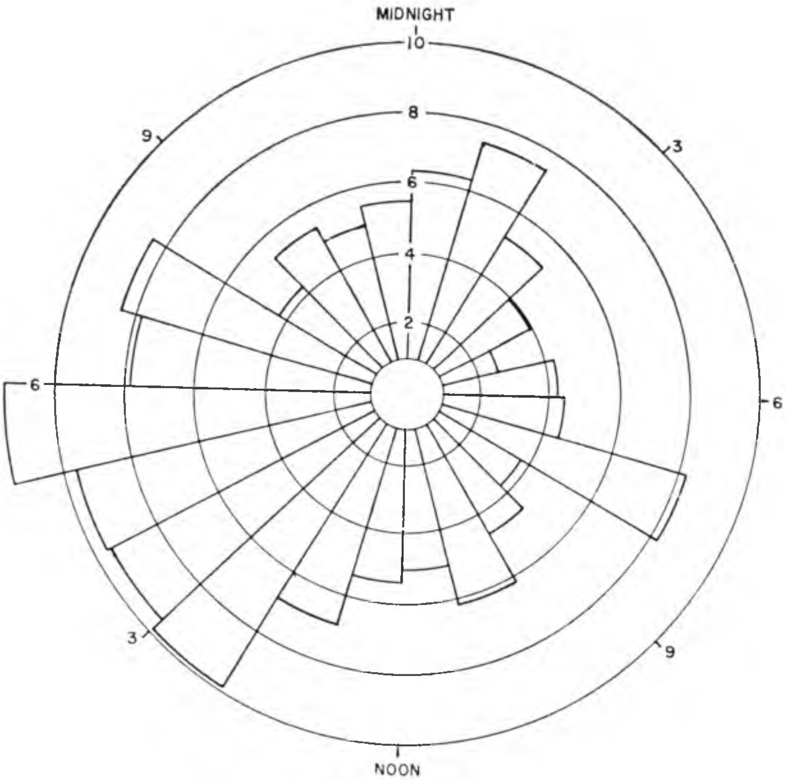

Fig. 15. Average annual accidents per million vehicle miles by hour of day for 1961, 1962 and 1963.

Other Analyses

Hour of Day—As shown in Figure 15, the following hours had accident rates above 6.87 accidents per million vehicle miles, the three-year-average accident rate for the bypass.

Hour	*Accident Rate*
1-2 A.M.	7.5
7-8 A.M.	8.2
1-2 P.M.	6.9
2-3 P.M.	9.8
3-4 P.M.	9.5
4-5 P.M.	9.6
5-6 P.M.	11.4
6-7 P.M.	7.8
7-8 P.M.	8.3

These hours represented 37.5 percent of a day but had 62.5 percent of the daily accidents, 59 percent of the injuries and 50 percent of the fatalities.

According to *Accident Facts, 1964,* (1) "During the first few hours after midnight, fatal motor-vehicle accidents reach a peak rate nearly ten times higher than the low rate for the day which occurs during the late morning hours." This peak, although somewhat smaller, was also experienced in this study from 1-2 A.M. for accident rates rather than death rates. Those driving during this hour are probably more tired and less alert than the daylight driver. Approximately 37 percent of the accidents that happened during this hour were single-car accidents.

The hour beginning at 7 A.M. is the morning rush hour and the hour beginning at 5 P.M is the evening peak hour.

Above average accident rates were found from 1 P.M. until 8 P.M. with the highest rates from 2 P.M. until 6 P.M. During this period a high percentage of the traffic is local while a substantial number of through-trip drivers are also trying to reach their destinations in Chicago or Indianapolis before evening. This combination of through and local trips, having different flow characteristics and operating under traffic congestion conditions, undoubtedly create a high accident potential.

Day of Week—Monday, Tuesday, Wednesday and Thursday had nearly the same accident rates. (See Figure 16). Friday and Saturday accident rates were about one and one-half (1½) that of the weekday average and Sunday accident rates were nearly twice the weekday average. Sunday had more accidents but fewer vehicle miles driven than any other day of the week. The "Sunday driver" apparently is at his worst on this facility. One reason for this increase in accidents on Sundays might again be due to the difference in flow characteristics. Some drivers are pleasure riding with their families and are in no hurry while other drivers are making intercity trips and would like to bypass the cities as quickly as possible. The differences in speeds

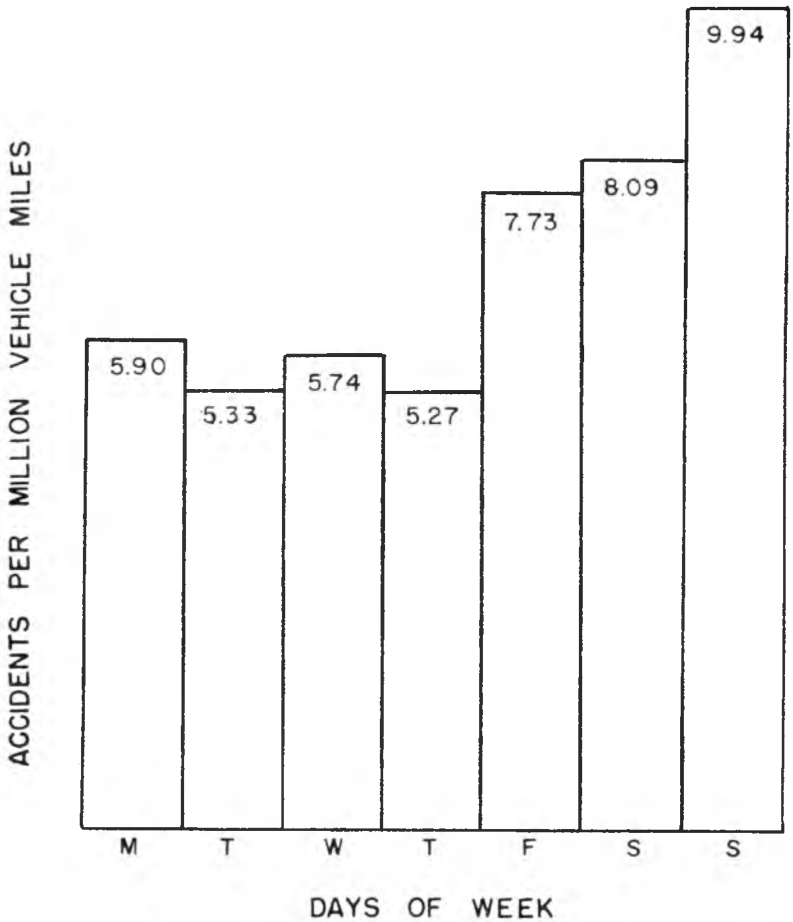

Fig. 16. Average accident rates by day of the week for 1961, 1962 and 1963.

and alertness of these drivers to other vehicles probably account for many accidents.

Month of Year—At first glance accident rates versus the months of the year (see Figure 17) appear to follow no pattern unless it might be one month with a high accident rate followed by a month with a low accident rate. However, further examination showed that the seven months with 31 days were those with the highest accident rates while the four months with 30 days were the months with the lowest accident rates. February, with 28 days, was in between these two groups. Since the accident rate, containing volume as a factor, already

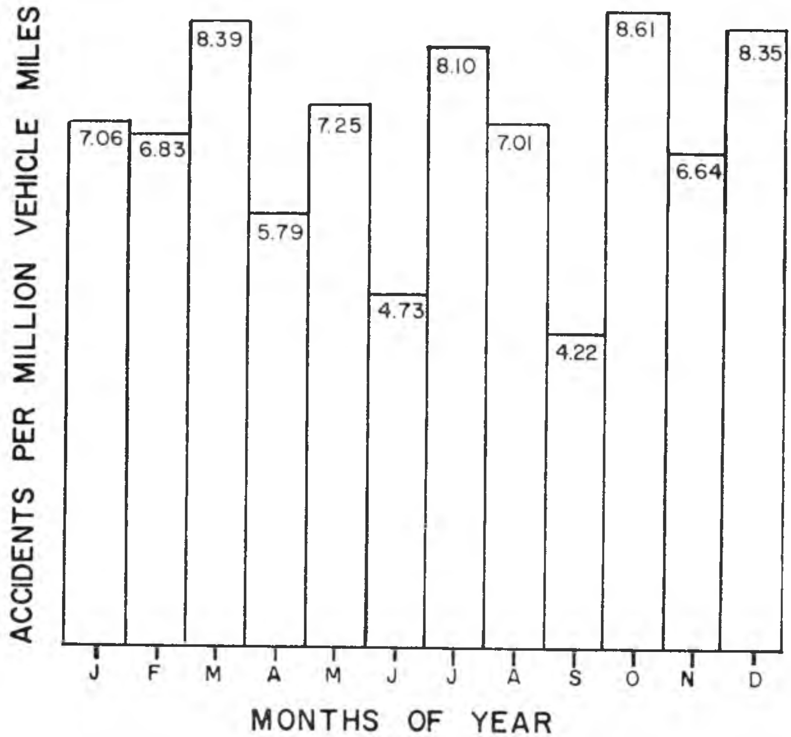

Fig. 17. Average accident rates by months of year for 1961, 1962 and 1963.

takes into account that one group had more days and since the difference in accident rates was too great for the difference in the number of days involved (31-day-month average accident rate was 7.8 while the 30-day-month average was 5.3), it was believed that this particular relationship (the number of days in the month) was coincidental. Another analysis provided some interesting explanations.

Four of the major holidays, Memorial Day, Fourth of July, Christmas and New Years Day, are in these high accident months and produce high traffic volumes. These months also had an average of 3.0 inches of precipitation per month while the others had 2.3 inches per month. March was second only to July for the amount of precipitation per month. Saturdays in October with Purdue home football games had nearly three times the number of accidents as the average number of accidents for Saturdays. Memorial Day not only brings the regular holiday traffic through the bypass but Indianapolis 500 traffic completely congests the bypass for several hours. July and August have the highest ADT's of all months. November with Thanksgiving has the highest accident rate of the 30-day-month group. In general then, high traffic volumes with a large percentage of through traffic and inclement weather are responsible for at least a part of the high accident rates in the 31-day months.

Weather—Precipitation data (20) and accidents by hour and data by hour were used to determine accident rates for weather that was clear or that was rainy or snowing. The comparative rates are shown in Figure 18. These extreme differences in rates clearly state that the occurrence of precipitation and accident rate were highly correlated on the bypass. The much higher rate on this facility during precipitation than normally found is undoubtedly the result of the fact that this facility is operating far above practical capacity for many hours of the day.

Severity—The ratio of fatal accidents to injury, to property damage, and to total accidents was approximately 1:25:85:111 for intersections and 1:17:38:56 for nonintersection study sections. The overall ratio for the bypass was 1:21:61:83. The same ratio for Indiana in 1963 was 1:33:97:131.

SUMMARY OF RESULTS AND FINDINGS

The results and findings of this accident research study of the U.S. 52 Bypass at Lafayette, Indiana, are summarized in the following paragraphs:

General

1. The number of accidents on U.S. 52 in Fairfield and Wabash Townships increased approximately 50 percent from 1956 to 1964.
2. Approximately 57 percent of the bypass accidents occurred within 100 feet of an intersection while about 65 percent happened within 200 feet of an intersection.

Multiple Linear Regression

1. This statistical technique provided a means of determining the independent variables that were significant in predicting various accident rates.
2. The developed regression model for accidents per 100 million vehicles accounted for 76 percent of the variability in the intersection accident rate on the bypass. The model for accidents per 100 million vehicle miles accounted for 33 percent of the variability in the nonintersection accident rate on the bypass.

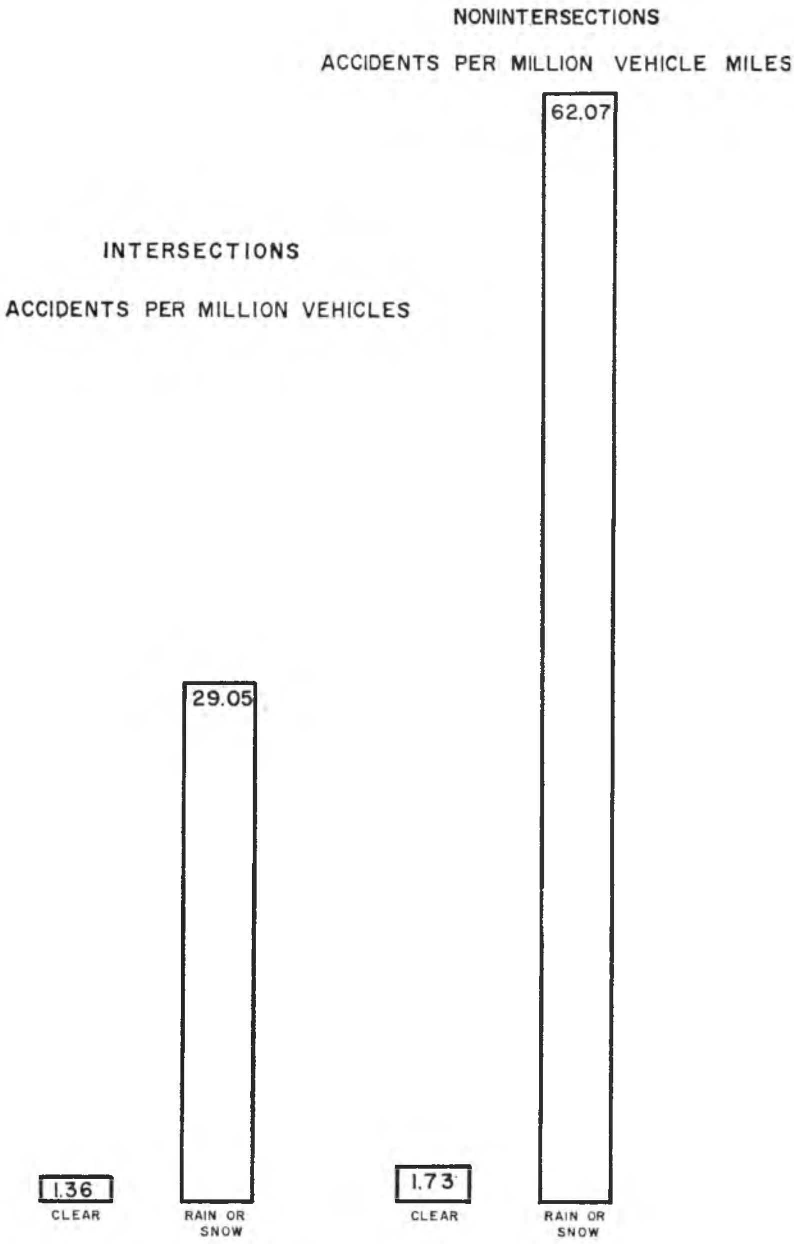

Fig. 18. Average annual accident rate for clear and inclement weather for 1961, 1962 and 1963.

3. For intersections, accidents per 100 million vehicles increased when:
   a. Percent green time on the bypass decreased
   b. Bypass or cross street ADT increased
   c. Percent left turns from the bypass increased
   d. Maximum approach speed increased
   e. Number of intersection approaches increased
   f. Total width of driveways within 200 feet of the intersection increased

4. For nonintersection study sections, accidents per 100 million vehicle miles increased when:
   a. Total number of establishments per mile increased
   b. Total number of driveways per mile increased
   c. Total number of low volume intersections per mile increased
   d. Geometric modulus increased
   e. ADT increased
   f. Operating speed decreased
   g. Total width of driveways per mile increased
   h. Length of intersection turning lanes in the section increased

Quality Control

1. Quality control analysis is an excellent technique for determining those sections or intersections of a highway that are "out of control" and probably have an assignable cause for the high or low accident rate.
2. Intersection number 14 (Teal Road) was out of control the two years prior to the installation of a traffic signal and also during the first year in which the signal was in use.
3. Those intersections consistently above the average accident rate were numbers 13 (S. R. 38) and 14 (Teal Road) while those consistently below average were 2 (Yeager), 7 (Underwood), 11 (Kossuth) and 12 (McCarty).
4. Nonintersection study section number 4 was out of control in both 1961 and 1962 but in 1963 had no accidents. Sections 18 and 19 were out of control in 1963.
5. In the three year study period those sections consistently below the average were sections numbered 2, 5, 6, 8, 10, 16, 20 and 24. Those consistently above average were sections numbered 14, 17, 18, 19 and 21.

Accident Rates

1. The number of accidents per million vehicles includes a consideration of exposure and is highly correlated with the severity and cost of accidents on the bypass. This accident rate provided a satisfactory measure of the hazard at an intersection and was used in comparing intersections in other parts of this study.
2. The intersections ranked as the most hazardous were 14 (Teal Road), 10 (S. R. 26), 6 (S. R. 25) and 8 (Greenbush) in decreasing order of hazard.
3. Those intersections ranked as the safest intersections were 2 (Yeager), 11 (Kossuth), 7 (Underwood), 12 (McCarty) and 5 (Ninth Street Cutoff) in increasing order of hazard.
4. Accidents per million vehicle miles, the most commonly used accident rate for sections of highway, was used to compare nonintersection study sections on the bypass. This rate was found to be correlated with accident cost and injury accidents per million vehicle miles.
5. The nonintersection study sections ranked as the most hazardous were 14, 17, 18, 19 and 21. Those considered the safest were 2, 3, and 24.

Collision Diagrams

1. There is no substitute for the use of collision-condition diagrams for the determination of specific causes of accident rates at intersections as well as nonintersection study sections.
2. The installation of traffic signals on the bypass during the study period (at the intersections with Salisbury, S. R. 38 and Teal Road) resulted in an increase in rear-end collisions, lane-changing accidents, injury accidents and total accidents in each case. While vehicles on the bypass were involved at a much higher rate after the signal installations, cross street traffic involvement rates remained the same or decreased. Right-angle and left-turn accidents also decreased.
3. Following the construction of extra approach and recovery lanes (a "passing blister") at Ninth Street Cutoff in 1962 a reduction of 50 to 80 percent of all types of accidents was realized.
4. A substantial number of accidents at intersections occurred when vehicles changed lanes or passed left-turning vehicles on the right.

5. Several accidents occurred when two vehicles passing through the intersection side-by-side were forced into the same lane when the exit lane terminated.
6. The left-turn movement of bypass traffic from the bypass to Northwestern Avenue is a dangerous one. Another hazardous movement is the left turn on to the bypass by U.S. 52 traffic at Northwestern Avenue.
7. During the three year study, 23 of the 31 accidents at Happy Hollow Road involved west bound vehicles nearing the crest of this steep hill. In addition to the limited sight distance, the fastest moving west bound vehicles were also in the same lane as left-turning vehicles because of a slow traffic climbing lane on the right.
8. Nearly one-third (18) of the accidents at S. R. 25 (the third most hazardous intersection) resulted from improper lane usage. Ten of these accidents happened in approach lanes and eight in exit lanes.
9. All of the 14 accidents at Underwood Street during the three year period involved left-turning vehicles. Thirteen of these accidents involved north bound vehicles.
10. At Greenbush Street all types of accidents increased in 1963 over 1962 or 1961.
11. The Union Street intersection accident rate for 1962 was about one-half that of 1961 or 1963.
12. South bound vehicles had a higher involvement rate than the other directional involvement rates at S. R. 26, the second most hazardous and the busiest intersection on the bypass. On the bypass as a whole, north bound vehicles had the highest involvement rate.
13. Ten of the 15 accidents at Kossuth Street involved left-turning vehicles. Seven of these ten involved north bound traffic.
14. At McCarty Lane four accidents were right-angle collisions while six others involved south bound vehicles changing lanes.
15. Rear-end accidents occurred four times as often after the traffic signal installation at S. R. 38 as before. The number of bypass vehicles in accidents more than doubled after the change while the number of vehicles on the cross streets involved in accidents decreased by 25 percent.
16. All methods used in this study indicated that Teal Road was the most hazardous intersection on the bypass. Following the

installation of the traffic signal in January 1963, rear-end and lane-change accidents increased by a factor of eight. The only type of accident to decrease was left-turn accidents. Left-turn lanes were constructed on the bypass when the signal was installed.

17. On the Wabash River Bridge six of the nine accidents occurred when the pavement was wet or icy.
18. Seven of the 11 accidents on section 10 happened at night. Six of the total accidents were on wet or icy pavement.
19. One-half of the nonintersection accidents occurred on sections 17 through 21. On this 1.6 miles of highway, 58 percent of the accidents involved marginal friction, two-thirds of the accidents occurred during the peak accident rate hours and 35 percent of the accidents occurred when the pavement was wet or icy.

Other Analyses

1. Over 62 percent of the daily accidents occurred during the hours from 1-2 A.M., 7-8 A.M. and 1-8 P.M. During these nine hours 59 percent of the injuries and 50 percent of the fatalities occurred.
2. Friday and Saturday accident rates were one and one-half that of the weekday rates while Sunday accident rates were nearly twice that for the weekday.
3. High volumes of traffic and inclement weather were factors which contributed to the high accident rate in 31-day months.
4. Inclement weather (rain or snow) accident rates were 21 and 36 times greater than clear weather accident rates for intersections and nonintersection study sections respectively.
5. The ratio of fatal accidents to injury, to property damage, and to total accidents was approximately 1:21:61:83 for the U.S. 52 Bypass as compared with 1:33:97:131 for Indiana in 1963.
6. Weekend accident rates were greater than weekday accident rates and day accident rates were higher than night accident rates. These comparisons were true for intersections as well as nonintersection study sections.
7. Sixty-one percent of the accidents that occurred on the days that had three or more accidents happened while it was raining or snowing. Friday, Saturday or Sunday also had 61 percent of these accidents.
8. The total cost of accidents on the U.S. 52 Bypass during the three year study period was nearly one million dollars.

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