JOINT HIGHWAY RESEARCH PROJECT

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ANALYSIS OF MOTOR VEHICLE
ACCIDENTS AT COMMERCIAL
DRIVEWAY LOCATIONS

David Albert Uckotter

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Final Report

ANALYSIS OF MOTOR VEHICLE ACCIDENTS AT COMMERCIAL DRIVEWAY LOCATIONS

TO: J. F. McLaughlin, Director June 19, 1974
Joint Highway Research Project
Project: C-36-59S

FROM: H. L. Michael, Associate Director
Joint Highway Research Project File: 8-5-19

Attached is a Final Report on a JHRP Research study titled "Analysis of Motor Vehicle Accidents at Commercial Driveway Locations". The research was performed and the report written by Mr. David Albert Uckotter, Graduate Assistant in Research on our staff. The research was directed by Professor G. T. Satterly.

This research is another in our series devoted to the objective of minimizing the detrimental effects of driveways on arterial streets. The findings of this study indicate those commercial activities that generate the largest number of accidents at their access points and that driveway and roadway volumes are the most significant factors involved in driveway accidents. A model is developed which predicts driveway accidents per mile for fully developed arterial highways serving commercial land uses.

The findings of this research are useful in predicting driveway accident rates on arterial highways through commercial land uses and in providing an estimate of the benefits which would occur from the reduction of the number of medium and high volume driveways on such a highway.

The Report is submitted as fulfillment of the objectives of this Study.

Respectfully submitted,

Harold L. Michael
Associate Director

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DRIVEWAY LOCATIONS

by

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Graduate Assistant in Research

Joint Highway Research Project

Project No.: C-36-59S

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ABSTRACT

Uckotter, David Albert. M.S.C.E., Purdue University, May, 1974. Analysis of Motor Vehicle Accidents at Commercial Driveway Locations. Major Professor: Gilbert T. Satterly, Jr.

The purpose of this research project was to determine the significance of driveway accidents on commercial arterial highways; to examine roadway, driveway and land use characteristics related to driveway accidents; and to determine which factors (land use, driveway and/or roadway) had significant effect on driveway accidents.

Data necessary for the study was collected in five central Indiana cities for 14 roadway sections. Accident data for a three year period were used to develop the dependent variables. In this sample of driveway accidents it was found that one-third of all traffic accidents on sections of arterial highways serving commercial land uses were driveway accidents.

Stepwise regression analysis was performed at three levels. At the first two levels, interactions among terms proved to be good predictors of driveway accidents. It was found that the driveway volume and combinations of the roadway and driveway volumes were significant in predicting driveway accident rates.

A model was also developed to predict the number of driveway accidents per mile per year of a roadway section serving commercial land uses. It was found, for the data of the study, that the roadway ADT, the ratio of medium plus high volume driveways per mile divided by the total driveways per mile, and the driveway volume per mile, predicted

82.6% of the variability of the driveway accidents per mile per year.

INTRODUCTION

"Property-fronting landowners have certain rights of access consistent with their needs, and road users have certain rights to freedom of movement, safety and efficient expenditures of their public highway funds. It falls on the highway authority to regulate and control the location and design, and operation of access driveways to reconcile and, to the extent feasible, to satisfy the needs and rights of both (1)". The above reference presents the dilemma that highway engineers are facing today. The provision of access to property adjoining the roadway is generally a right of land ownership. One of the objectives of a highway engineer is to provide a roadway that is safe, efficient and will move people from one point to another in a relatively short period of time.

From past experience, it is seen that provision of unlimited access to all parcels of land, and construction of a roadway providing safe, efficient and fast movement of vehicles generally do not co-exist in the same location. Many of the problems on these roadways can be traced to the allowance of unlimited access (the lack of access control). A simple definition of access control is the restriction of access to selected locations along a roadway.

To design a roadway that is safe, one must design so as to reduce the number of potential accident hazards. Driveway accidents are a significant portion of the total number of accidents on a roadway (6,9,15,25,32). Further, most driveway accidents occur at commercial driveways as opposed to residential driveways (9,25).

A commercial driveway is defined as one providing access to offices, retail uses, institutions and apartment buildings having more than five dwelling units, and which customarily are serviced by trucks on an incidental rather than a principal basis. Many industrial plants have driveways servicing administrative or employee parking lots. These driveways are also considered as commercial driveways in this study. A residential driveway is one providing access to single family residences, duplexes and apartment buildings containing five or less dwelling units (35).

The development of the above commercial and residential driveway type classification is logical. Residential driveways serve very low volumes of traffic, never will require traffic control devices on the street, are narrow in width and are located on non-arterial and arterial roadways. Commercial driveways serve a very large range of traffic volumes, may require varying amounts of traffic control, are usually of two-lane or more in width and generally are located on arterial roadways with high traffic volumes.

Driveways are privately owned roads which connect buildings and adjoining grounds with public ways. In reality, driveway connections to public ways are intersections (7). The safety and efficiency of driveways depends on the traffic volumes of both the driveway and the roadway, configuration and the system of traffic control employed at the driveway. As driveways are truly additional intersections, the accident characteristics of intersections and driveways should be similar. These characteristics, in addition to questions concerning roadway characteristics, must be adequately determined in order to reduce the number of accidents at driveway locations. Roadway characteristics which might influence the driveway

accident rate include the presence or absence of parking, speed limit, roadway width, use of a median, left turn restrictions and many others.

Commercial driveways appear to be the major source of driveway accident production. The volume of traffic using a particular driveway would logically appear to be an important factor in driveway accident occurrence. Research involving commercial driveway volumes and other possible important characteristics should help to define relationships between variables and in the development of standards for the safe and efficient placement of driveways on commercial arterial highways.

LITERATURE REVIEW

There have been many studies undertaken in the area of traffic accident analysis. However, a relatively small number of these studies has concentrated on accident occurrences at driveway locations.

Driveway Accident Studies

Paul C. Box and Associates, over the past several years, has compiled substantial data concerning driveway accidents. Several of the conclusions of the Box studies are pertinent to this research. In one study (9) of 40 miles of traffic routes, using five years of accident data, in Skokie, Illinois, he found that

1. accidents at all types of driveways represented 11% of the total city accidents
2. driveway accidents accounted for 12% of the major route total and 9% of the minor street total
3. along major traffic routes, the rate at commercial driveways was 10 times the rate at residential driveways
4. left turns were involved in 60% of all driveway accidents, and in 75% of those producing injuries.
5. a great variation exists in accident rates as a function of type of commercial land use served
6. a general relationship was found between route ADT and driveway accident rates

7. no relationship was found when comparing driveway accident rates with the number of openings per mile, or with street width

Box indicated that factors such as traffic volume on the arterial highway, the number of lanes, parking conditions, spacing between driveways and adjacent intersections, and volume of traffic using the driveway should be studied in an analysis of driveway hazard. Bruggeman (11) discovered that driveway accidents are related to the number of driveways, type of driveways, median width and traffic volume on the highway. He determined that the number of commercial driveways per mile was the most significant indicator of the driveway accident rate. In terms of driveway geometrics, the Texas Transportation Institute discovered that driveway accident rates at driveways with uncontrolled width to be 4 times greater than those at driveways with a controlled width (41).

Box also studied accident rates as related to land use. This study revealed that driveways to Community Shopping Center produced 10.5 accidents per year per center, Neighborhood Shopping Centers 1.72 accidents per year per center, drive-in restaurants 1.34 accidents per year per restaurant and service stations 0.53 accidents per year per station (8).

McGuirk (25) studied driveway accidents and their relationships to roadway characteristics on urban arterial roadways. He studied 100 roadway sections, averaging 0.604 miles in length, located in ten central Indiana cities. He discovered that

1. 14% of all traffic accidents on the 100 sections were driveway accidents
2. Left turn movements, to or from a driveway, resulted in 64.6% of all driveway accidents. 76% of all driveway accidents resulting in personal injury involved a left turn maneuver.

3. The number of driveway accidents per mile per year will decrease when one or more of the following conditions occur:
 - a) the number of commercial driveways per mile is reduced
 - b) the number of through traffic lanes is reduced
 - c) the number of total intersections per mile is increased
 - d) the number of total driveways per mile is reduced
 - e) the arterial highway ADT is reduced.
4. The fewest number of driveway accidents occurred on Sunday, when traffic volumes are lowest and many business establishments are closed. The number of driveway accidents was significantly higher on Fridays and Saturdays, when traffic volumes reach their weekly peak and commercial establishments, on the average, do more business.

Traffic Accident Studies

Several traffic accident studies, both urban and rural in character, were made in an attempt to predict total traffic accident occurrence. The variables that were found to affect accident rates are significant.

Head's (19) study of urban highways in Oregon found that the frequency of commercial establishments per mile, number of traffic signals, number of intersections per mile, speed limit, volume and pavement width were important factors in prediction of accident occurrence. He also found that residential driveway frequency was one of the least significant predictors of driveway accidents.

Schoppert (37), using multiple correlation analysis, found that accident predictors included roadway volumes, frequency of driveways or intersections, lane or shoulder width and sight restrictions. Peterson (31) developed

regression equations that showed non-intersectional accidents increased when the number of driveways increased, the number of establishments increased, and the total number of low volume intersections increased.

Staffeld (39) studied the effect of access points on roadways in Minnesota. He discovered that the number of access points per mile and the ADT affected the traffic accident rate. Also, he found that accident rates for sections with driveways was twice as great as for sections without driveways. It was concluded that the increased rate reflected the increased use of access points to commercial establishments. Box stated that driveways are miniature "T" intersections and the higher activity land uses produced volumes greater than most intersections of local streets with major routes (8). Intersection accident rates appear to be sensitive to changes in the proportion of traffic flow from the various legs of the intersection. Studies indicate that an increase in major roadway volume has little effect on the accident rate, whereas an increase in volume or an increase in percentage of traffic, from the minor facility results in a rapid jump in the accident rate (20,24,34,44). Mulinazzi (27) reported that among the four major elements of correlation to urban arterial accidents was the number of heavily used driveways per mile. This factor suggests that possibly by studying the frequency of use of a driveway, another important factor might be uncovered in relating driveway accident rates to route and driveway characteristics.

Access Control

There are two types of roadway friction present on a commercial arterial highway. Internal friction results from interactions, such as weaving or passing, between vehicles on the arterial. Marginal friction is the

impedence that a traffic stream encounters along the perimeter of the highway. Principal sources of marginal friction are curb parking, truck loading zones, and slow-moving vehicles entering or leaving either a driveway or an intersecting street (33). Gwynn (18) found that 80% of all accidents on New Jersey's state highway system were the result of marginal friction.

In an attempt to reduce marginal friction along commercial arterials, several methods are available. Vehicle parking and loading zones could be prohibited. Also, controls on placement of driveways will reduce the number of vehicles in conflict on the arterial by limiting the number of ingress and egress points. The American Association of State Highway Officials (AASHO), in 1960, adopted a policy stating that frontages of 50 feet or less be limited to one driveway. Not more than two driveways need be permitted unless the frontage exceeds 600 to 1000 feet (1).

Many government organizations have driveway regulation ordinances. However, there is no uniform set of standards used for the development of those ordinances.

Driveway - Driveway and Driveway - Intersection Spacing

Research in the area of spacing of driveways from intersections and other driveways is generally limited to observation and vague recommendations for improvement. Matson, Smith & Hurd (22) suggest that if two driveways are necessary for one establishment, they should be located as far apart as possible.

The Texas Transportation Institute (42) found that parallel parking within 50 feet of a driveway seriously restricts sight distance of exiting driveway vehicles. As the traffic volume increased, closely spaced driveways

caused more, not less, congestion. They then concluded that adequate spacing should be provided in order to minimize interference, in the roadway, from two adjacent driveways. The state of Wisconsin (33) Highway Commission controls access to property on the state highway system. Access points along opposite sides of the highway either are located directly opposite each other or are separated from each other by 300 feet.

Stover (41) stated that no private access point should be permitted unless it is a high volume traffic generator. This can be accomplished by concentrating traffic conflicts at a single location, controlled by a traffic signal (33).

Box (7) stated that driveway connections to public ways are, in reality, intersections. In this sense, driveway-intersection spacing is similar to driveway-driveway spacing, and the above comments appear to again hold. In general, it is clear that the farther from an intersection, or another driveway, a driveway can be located, the less it will affect the arterial traffic.

PURPOSE

The lack of driveway accident studies on urban commercial arterial highways is apparent from the literature review. Inconsistencies in driveway design regulations have resulted in numerous ambiguities in driveway and intersection design standards. For example, higher design standards are sometimes required for low volume residential intersections than for high volume shopping center driveways. There is a definite need to improve the present methodology and clear up inconsistencies in the design standards of driveway location techniques.

The purpose of this research is to

1. evaluate the characteristics of commercial driveway accidents
2. relate commercial driveway accident rates to commercial driveway volumes
3. relate commercial driveway accident rates to roadway and driveway characteristics.

DATA COLLECTION

Selection of Roadway Sections

This study was a continuation of the research project by McGuirk (25), Evaluation of Factors Influencing Driveway Accidents. The procedure was similar to that used by McGuirk, with two modifications. The first was that the research studied only commercial arterials, containing as few residential driveways as possible. Secondly, the volumes of traffic that used particular driveways were included in the list of variables to predict driveway accident rates.

Delimitation of the study area was necessary before the individual roadway sections were selected. Sections included in the study came from cities in central Indiana whose population, as of the 1970 census, exceeded 35,000 and was less than 100,000. Further, the cities were chosen from the list compiled by McGuirk. Since a great deal of time was needed to obtain the driveway volume counts, the five northernmost cities were selected for study. From a survey of the roadway sections used by McGuirk, it was estimated that at least three roadway sections from each city could be obtained for study, providing a total of 15 sections.

Roadway Data

The initial task of identifying sections for the study required site inspections. In order to obtain valid results from the analysis, the sections had to form some sort of cohesive set. Since factors such as speed limit,

ADT, etc., could have an effect on the driveway accident rate, they had to remain constant throughout each study section. Therefore, in order to be included in the study, the sections had to meet the following criteria:

1. The section must be outside the central business district limits, but within the city's corporation limits.
2. The section must be an undivided highway with no changes in pavement width, roadway volume or parking characteristics.
3. No major land use changes had occurred within the past five years.
4. No major roadway reconstruction had occurred within the past five years.
5. The driveway accident rate for the first three years of data, for each section, must be similar.

With these five requirements in mind, roadway sections were located which would fulfill the first and second points. This was done by a general site inspection of the eligible sections. Next, the city building permit records were scanned to determine whether any major land use changes had occurred since January 1, 1968. The study period began January 1, 1969, so there would be a one-year adjustment period for traffic flow variations to disappear. The city engineer's offices provided data on major roadway improvements that were suspected of being built after January 1, 1968.

If a section met the first four requirements, selected data were collected for each section. This information included roadway characteristics such as section terminals, speed limit, parking, curb and shoulder characteristics and number of traffic lanes. At the same time, individual driveways, in each section, were identified and specific information collected. Data included side of street, number of driveways to each establishment, name of the

establishment using the driveway, description of the establishment, type of pavement, one-way or two-way use of the driveway, number of lanes on the driveway, whether a median was present in the driveway and presence of storage lanes or special traffic signals for turning movements into the driveway. Inventory sheets for the data are included in the Appendix.

The length of each section, the distances between driveways, between driveways and adjacent intersections, and widths of streets and driveways were obtained by use of a standard measuring wheel. The sections generally were begun at the nearside curb of an intersection and ended at the nearside curb of the final intersection. The width of each roadway section, from edge of pavement to edge of pavement, width of the lanes and width of shoulders, if present, were obtained in the same manner.

Accident Data

Accident data for the chosen sections were compiled for a period from January 1, 1969 to December 31, 1972. All of the data were collected from the accident records of the six police departments. Also, all information was obtained from the standard Indiana State Police accident report form filed by the investigating officer.

When a driveway accident was identified, pertinent data were recorded onto a separate inventory sheet. Data collected included time and location of the accident, type of lane use, accident severity, type of accident, prevailing weather conditions and probable cause of the accident. A copy of this inventory sheet is in the Appendix.

The first three years of accident data were used for the analysis of factors affecting the driveway accident rate, while the last year's data were used as a base to

test the results of the analysis. In parts of the descriptive analysis of driveway accidents, all four years of data were utilized.

The three year driveway accident record used in the analysis was to insure an adequate sample size of accident data, and reduce the possibility of including an unusual number of driveway accidents, as compared to other years, for a section. May (23) stated that a three year accident history is the minimum time period to be used in an accident study, and little is gained by using a longer period.

At this point, the fifth requirement, as outlined in the previous section, was checked. Due to the short data collection period available, and also to the difficulty in collecting driveway volumes, a preliminary analysis of variance test of the first three years of accident data, for each section, to determine significant differences from year to year, was conducted. If any of the sections previously selected failed this test, they were excluded from the study. One section did not pass this final requirement, and no substitute section in that city could meet all five requirements. This phase of the accident collection will be discussed at length in the analysis portion of the study.

Table 1 lists all of the cities included in the study. Also listed are the cities population, section name, section number, terminal points, length and 1970 ADT.

Roadway Traffic Volumes

Traffic volume data for the 14 sections were obtained from three different sources. Traffic counts for eight of the sections were obtained from the Indiana State Highway Commission, (ISHC), Division of Planning. Four volume counts were obtained from the records of the cities

Table 1. Selected Study Sections and Characteristics

City (Population)	Section Name	Section Number	Section Terminals	Section Length(mi)	Section ADT (1970)
Lafayette- West Lafayette (64112)	Teal	1	Edgelea-Crestview	.226	17196
	Main	2	16th-24th	.712	8126
	State	3	Brown St-1240' east	.235	19302
Kokomo (44042)	Sycamore	4	Berkeley-59' W of Devonshire	.218	9809
	Boulevard	5	US 31-Home St	.686	14992
	Markland	6	Buckeye-Plate	.875	16042
Marion (39607)	Adams	7	32nd-100' S of 37th St	.510	7737
	Baldwin	8	Winona-Kem	.526	16968
	Third	9	Gallitin-Hill	.248	6487
Muncie (69082)	Madison	10	13th-24th	.764	17400
	Jackson	11	Kilgore-White River Pkwy	.258	12298
	Jackson	12	Manning-667' W of Tillotson	.195	8796
Anderson	East	13	5th-8th	.210	19832
	Broadway	14	Grand-526' N of North St	.536	17500

of Kokomo and Anderson. The other two volume counts were obtained through field work, by placing 24-hour traffic counters at selected locations on the roadway sections.

Information was collected in the form of hourly volume counts, in order to identify peak hourly volumes for comparison with accident occurrence.

The average daily traffic (ADT) for each section was derived from the average 24 hour weekday volume count. Expansion factors supplied by the ISHC were used, from the category for "State Roads in Suburban Areas", to obtain the appropriate ADT. In cases where only 1973 volume counts were available, 1972 factors for the same month were applied to obtain the ADT for that section. Table 2 lists the expansion factors used in the study.

An ADT growth rate of 4% is assumed by the ISHC. By using this growth rate, ADT figures for each year were generated for the study. A listing of the 1970 ADT's is included in Table 1.

Driveway Volume Data

Due to the short period of time, and difficulties of collection of driveway volume data for long periods of time, a method of estimating volumes from sample counts was developed. The first step was to formulate a land use classification table. All of the land uses in the study were then placed in respective categories. From an inspection of accident records, land use categories with high accident rates were identified. Then, certain establishments in each category were selected for purposes of making a 12 hour volume count of their driveway movements. These driveway volume data were then plotted on an hourly graph. For additional establishments in those categories, volume counts ranging from two to ten hours were taken. It was assumed that the trends of movement to and from a land use would remain fairly constant, but

Table 2. Factors to Expand 24 Hour Weekday (Monday, Tuesday, Wednesday, Thursday)
Volumes to ADT (State Roads in Suburban Areas)

Month of Year	Year			
	1969	1970	1971	1972
January	1.239	1.208	1.222	1.154
February	1.141	1.144	1.210	1.066
March	1.071	1.031	1.073	1.008
April	1.025	1.067	1.025	0.952
May	0.954	0.988	0.987	0.924
June	0.949	0.950	1.040	0.920
July	0.931	0.942	0.924	0.958
August	0.925	0.928	0.931	0.973
September	0.967	0.919	0.931	0.972
October	0.984	0.943	0.944	0.990
November	1.007	0.970	0.967	1.002
December	1.028	0.985	0.962	1.053

the magnitude, from one establishment to another, would vary. As an example, one neighborhood shopping center was counted for a 12 hour period. The volume counts were plotted as an hourly graph. Another neighborhood shopping center was counted for a period of six hours and these data were also plotted on the graph. It was assumed that the shapes of the curves were roughly similar, but that the magnitude of the second curve varied in relation to the first. The volume for the second shopping center was estimated from the shape of the first curve, by extending the second curve in a similar shape to the first curve.

This process was utilized for all of the establishments in the study sections. A more detailed explanation will be presented in the next chapter.

Actual driveway volume counts were taken manually, and listed on standardized collection sheets. The volume count itself was taken in 15 minute intervals and turning movements were listed separately in all cases. In that way, right turn in, right turn out, left turn in and left turn out movements were recorded in 15 minute intervals. Peak in or out, right or left turn movements were then identified.

Pneumatic-tube counters were placed at several one-way driveways to determine their usefulness in the data collection. However, due to erratic driveway movements, and the available equipment, they were not adequate for use in this study.

Questionnaire Data

The questionnaire distributed to the store managers was meant to draw out facts, and possibly trends, not readily noticeable from a one day volume count. These factors included busiest months of the year, busiest

days of the week, busiest hours, or periods, of the day, and how many hours of the day the establishment was open.

The questionnaire was also useful in estimating the driveway volumes present at certain locations. These facts were used to help estimate volumes on other driveways which had less catalogued data. A copy of the questionnaire is included in the Appendix.

ANALYSIS OF DATA

Land Use Classification

In order to draw conclusions on accident occurrence according to land use, a land use classification table was developed, and is shown in Table 3. This table is derived from the Standard Land Use Coding Manual (40). Several categories and subcategories were deleted from the federal classification, since there were no driveways in those categories. Then the remaining categories were renumbered, for continuity. The major addition to the classification was the first category, General Trade. This type of format for the first category was chosen to identify driveways that serve two or more land uses, and to separate them into groups. The subcategories were defined as follows:

Community Shopping Center--include shops such as convenience goods, personal services, supermarket, drugstore, wearing apparel, appliances, variety store and small department store (13).

Neighborhood Shopping Center--include shops such as convenience goods, personal services, supermarket and drug store (13).

Department Store--includes major department store

Community Parking Lot--include small number of land uses, of a general nature, using a common parking lot and common driveways.

All of the other land use classifications are standard and self-explanatory.

The land use classification was used to determine differences in driveway volumes and driveway accident

Table 3. Land Use Classification

1. TRADE

General

- 111 - Community Shopping Center
- 112 - Neighborhood Shopping Center
- 113 - Department Store
- 114 - Community Parking Lot

Food

- 121 - Supermarket
- 122 - Grocery

Automotive

- 131 - Auto Dealer (New and Used)
- 132 - Auto Dealer (Used)
- 133 - Auto Parts
- 134 - Gas Station (Garage)
- 135 - Gas Station (Gas Only)
- 136 - Gas and Wash

Eating and Drinking

- 141 - Restaurant (Dining Only)
- 142 - Restaurant (Dining and Carry Out)
- 143 - Tavern-Bar-Cafe

Other

- 151 - Drugs - Pharmacy
- 152 - Liquor Store
- 153 - Other Trade

2. SERVICE

Finance

- 211 - Bank
- 212 - Real Estate - Insurance

Personal

- 221 - Laundromat
- 222 - Dry Cleaner - Laundromat
- 223 - Equipment Rental

Repair

- 231 - Auto Repair
- 232 - Auto Wash

Other

- 241 - Elementary School
- 242 - Warehousing
- 243 - Other Services

Table 3. (Continued)

3. MANUFACTURING

General

311 - Manufacturing

4. RESIDENTIAL

Group

411 - Multi-Family Residential

Household

421 - Single-Family Residential

5. TRANSPORTATION

Highway and Right-of-Way

511 - Streets

512 - Alleys

6. RECREATION

Commercial

611 - Bowling Alley

General

621 - Parks

7. VACANT

General

711 - Vacant - Commercial

712 - Vacant - Other

rates from category to category.

Accident Variability

In order to develop an analysis that provided accurate information, the sample being studied had to meet certain requirements. The validity of the three years accident data used in this study, had to be established. It was agreed that suitable validity would exist if there were no significant differences between any of the three years of accident rates for each section in the study.

One method of determining significant differences between values was by using a 1-way Analysis of Variance (ANOVA) test, for each section in the study. The treatments used were the various land use categories and/or subcategories from the land use classification table, and the observations were the number of accidents occurring for each land use in the three years of study. Because there were unequal numbers of driveways in each land use, each driveway was listed, by number of accidents, for each of the three years of observation. A general table would appear as in Table 4, where the d_{111} represents the number of accidents that occurred at the first driveway in the first year at the first land use, d_{112} represents the number of accidents that occurred at the second driveway in the first year at the first land use, etc.

An example will easily explain the analysis. Section 1, Teal Road, in Lafayette, was 0.226 miles long, contained 9 driveways and no intersections, although both terminals to the section were intersection. There were 5, 11 and 13 driveway accidents in the three years, respectively. When these figures were placed in tabular form, Table 5 was produced. It was seen that the first driveway in the "Trade, Automotive" group had 1 accident in 1971, 1 accident in 1970 and 0 accidents in 1969. The second

TABLE 4. ACCIDENTS PER DRIVEWAY PER YEAR

YEAR	LAND USE CATEGORY (SUBCATEGORY)			
	1	2	...	t
1	d ₁₁₁ d ₁₁₂ ⋮	d ₂₁₁ d ₂₁₂ ⋮	⋯ ⋯ ⋮	d _{t11} d _{t12} ⋮
2	d ₁₂₁ d ₁₂₂ ⋮	d ₂₂₁ d ₂₂₂ ⋮	⋯ ⋯ ⋮	d _{t21} d _{t22} ⋮
3	d ₁₃₁ d ₁₃₂ ⋮	d ₂₃₁ d ₂₃₂ ⋮	⋯ ⋯ ⋮	d _{t31} d _{t32} ⋮

TABLE 5. ACCIDENTS PER DRIVEWAY PER YEAR FOR TEAL RD.

YEAR	LAND USE CATEGORY (SUBCATEGORY)				
	TRADE AUTOMOTIVE	TRADE FOOD	TRADE GENERAL	RECREATION GENERAL	TOTAL
1969	1 0	0 2	3 1 2	4 0	13
1970	1 1	1 0	0 6 1	1 0	11
1971	0 0	0 0	2 2 1	0 0	5
TOTAL	3	3	18	5	29

driveway had 0 accidents in 1971, 1 in 1970 and 0 accidents in 1969. The other groups thus follow.

To obtain valid results from the ANOVA, the variances of all of the cells had to be equal. In order to verify this, a homogeneity of variance test of the cells was performed, using the stored computer program, DATASUM. This program generates a value known as a Q statistic (39) for the data. For equal sample sizes, n , from each of p parent populations, s_j^2 ($j = 1, p$) denotes the j th sample variance. Denoting the value of the test statistic Q by q

$$q = (s_1^4 + \dots + s_p^4) / (s_1^2 + \dots + s_p^2)^2$$

For unequal sample sizes, each sample variance, s_j^2 , is calculated by dividing by the degrees of freedom, v_j , rather than the sample size, n_j ($v_j = n_j - 1$, for $j = 1, p$). Let $\bar{v}$ denote the arithmetic average of the degrees of freedom. Then,

$$q = \bar{v} (v_1 s_1^4 + \dots + v_p s_p^4) / (v_1 s_1^2 + \dots + v_p s_p^2)^2$$

Large values of Q lead to rejection of the hypothesis of equal population variances. For large sample sizes ($v > 10$), $p\bar{v} (pQ - 1) / 2$ is asymptotically Chi-square with $(p - 1)$ degrees of freedom. The critical value for the test is read from a table of critical Q values, at the 0.999 level. If the computed value is less than the table value, the hypothesis is accepted. If the computed value is greater than the critical value, a square root transformation of the data, due to its Poisson nature, could be performed, or, if that failed, the cells would have to be rearranged, and the procedure repeated.

In the case of section 1, the variances of the cells were homogeneous without transformation. Since homogeneity of variance was satisfied, normality could also be safely assumed. The F-test is quite strong even without

normality being satisfied (30). The ANOVA was performed with the data in the form of Table 5. A computer program, called UNEQUAL, was used, and the results are in Table 6.

Using a test level of 0.95 for the F-test, the critical value for $F_{.95(2,21)} = 3.47$. Since the calculated F ratio of 1.06 was less than 3.47, the hypothesis of no significant differences in the number of accidents over years was accepted.

This procedure was used for all sections in the study. Of the 15 sections, one failed to pass the tests, and was rejected. A search for another section, in that city, to be included in the study was unsuccessful.

Analysis of the Questionnaire Data

The questionnaire sent to the store managers was intended to be useful in determining the busiest month of the year, busiest day of the week, busiest periods of the day and their relationships to the driveway accident rate were established.

143 questionnaires were returned by the store managers. Of these, 46% listed the last quarter of the year as the busiest months of the year, 50% of the managers listed Friday as the busiest day of the week, 42 establishments designated the afternoon as the busiest period of the day, while 44 listed the evening as the busiest.

By segregating the questionnaires by type of lane use and driveway volume, different factors appeared. Shopping centers, supermarkets, restaurants and pharmacies were busiest in the last quarter of the year. Other retail, such as automotive related business (including gas stations) and personal, repair and other services were busiest in quarters other than the fourth. Dining and carry-out restaurants and financial services were generally split, with half being busiest in the fourth quarter, and the other half being spread over the other three quarters.

TABLE 6. ANALYSIS OF VARIANCE TABLE FOR TEAL ROAD

SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F - RATIO
TREATMENTS				
YEARS	3.85	2	1.93	1.06
LAND USE	12.02	3	4.01	2.22
ERROR	37.98	21	1.81	

Of the total number of establishments listing the last quarter of the year as the busiest period of the year, 36% listed afternoon as the busiest period of the day, 30% listed evening as the busiest period, while the remaining listed some other period or none at all.

The results of the questionnaire survey were not of the quality expected. Many managers refused to answer several questions. Some managers were new and did not have any knowledge of previous store volumes, or merely guessed at the answers. As a result, further analysis of this information was not considered to be of benefit to the project.

Driveway Data

On the 14 sections included in this study, there were 434 driveways located on 6.199 miles of roadway. The sections contained between 9 and 73 driveways. This includes all types of curb cuts, with the exception of streets intersecting the study sections. Driveway widths ranged from 7 feet to 95 feet, with the average driveway being 26.8 feet wide. The average driveway width per section ranged from 36.2 feet on Baldwin Avenue to 20.3 feet on Third Street, both in Marion. The average number of driveways per mile ranged from 37.90 driveways on Boulevard, Kokomo, to 104.76 on East, Anderson. By cataloging the driveways according to land use, there were 49 driveways serving gas stations with garages, 50 dining and carry-out restaurant driveways and 39 driveways serving community parking lots.

There were 279 establishments served by the 434 driveways, where 156 establishments had one driveway, 100 had 2 driveways, 19 had 3 driveways, 3 had 4 driveways and one had 9 driveways. There was an average of 1.56 driveways per establishment. The number of driveways and

number of driveways per mile are listed, by section, in Table 7. The number of establishments, number of driveways and number of driveways to the establishments are listed by land use in Table 8.

Driveway Volume Data

Driveway volume counts were conducted manually on all driveways on the study sections. However, due to the large number of driveways and to the short time allotted to volume collection, a method to estimate driveway volumes was developed. As mentioned earlier, all the driveways were classified by land use, into various groups. For example, all neighborhood shopping centers were placed in the same classification. Then, certain assumptions were made. First, it was assumed that the establishments for that land use classification exhibited a traffic flow that was typical from day to day, i.e., the peak hour remained the same from Monday through Thursday. Secondly, that the characteristics of the establishments (such as peak business periods, hours of operation, etc.) in a particular land use classification remained similar. Thirdly, that the establishment used as a base in each classification exhibited characteristics that were common to all other establishments in that classification.

By making these assumptions, it was possible to make at least one driveway volume count for 12 hours, for one classification, and by using that count as a base, to estimate all other volume counts for that classification. Volume counts per establishment were used in this study, since the individual driveway volume counts exhibited too much variability.

The following example describes the procedure. Classification 112, Neighborhood Shopping Center, consisted of two such centers (establishments). Both

Table 7. Accident Characteristics by Section

Section	Number of Driveways	Driveways Per Mile	Number of Accidents 4yr. 3yr.	Accidents Per Mile Per Year 4yr. 3yr.	Accidents Per Driveway/Year 4yr. 3yr.
1	9	39.82	37 29	40.93 42.77	1.03 1.07
2	39	54.78	24 20	8.43 9.36	0.15 0.17
3	22	93.62	54 44	57.45 62.41	0.61 0.67
4	11	50.46	9 6	10.32 9.17	0.21 0.18
5	26	37.90	94 60	34.25 29.15	0.90 0.77
6	73	83.43	71 58	20.29 22.10	0.24 0.27
7	27	52.94	30 20	14.71 13.07	0.28 0.25
8	51	96.96	65 45	30.89 28.52	0.32 0.29
9	12	48.39	9 8	9.07 10.75	0.19 0.22
10	68	89.01	57 42	18.65 18.32	0.21 0.21
11	16	62.02	10 7	9.69 9.04	0.16 0.15
12	16	82.05	15 8	19.23 13.68	0.23 0.17
13	22	104.76	14 12	16.67 19.05	0.16 0.18
14	42	78.36	56 51	26.12 31.72	0.34 0.37

Table 8. Accident Characteristics by Land Use

Land Use Code	Number of Establishment	Number of Driveways	Driveways Per Establishment	Number of Accidents 4yr.	Number of Accidents 3yr.	Accidents Establishment 4yr.	Accidents Per Establishment 3yr.	Accidents Per Driveway 4yr.	Accidents Per Driveway 3yr.
111	2	4	2.00	56	36	7.00	6.00	3.50	3.00
112	3	7	2.34	45	30	3.75	3.34	1.61	1.43
113	1	2	2.00	11	10	2.75	3.34	1.38	1.67
114	19	39	2.05	63	49	.83	.86	.40	.42
121	3	8	2.67	11	11	.92	1.22	.34	.46
122	6	8	1.33	10	6	.42	.33	.31	.25
131	5	12	2.40	7	6	.35	.40	.15	.17
132	6	7	1.17	2	1	.08	.06	.07	.06
133	2	2	1.00	5	3	.63	.50	.63	.50
134	25	49	1.96	34	26	.34	.35	.17	.18
135	12	24	2.00	30	26	.63	.72	.31	.36
136	1	2	2.00	1	1	.25	.33	.13	.17
141	7	13	1.86	14	9	.50	.43	.27	.23
142	29	50	1.72	89	77	.77	.89	.45	.51
143	6	9	1.50	14	11	.58	.61	.39	.41
151	3	4	1.34	9	6	.75	.67	.56	.50
152	4	7	1.75	3	3	.19	.25	.11	.14
153	17	22	1.29	8	6	.12	.12	.09	.09
211	6	10	1.67	23	16	.96	.89	.58	.53
212	5	6	1.20	1	1	.05	.07	.04	.06
221	2	4	2.00	4	2	.50	.33	.25	.17
222	5	5	1.00	5	3	.25	.20	.25	.20
223	2	3	1.50	0	0	.00	.00	.00	.00

Table 8. (Continued)

Land Use Code	Number of Establishment	Number of Driveways	Drivers Per Establishment	Number of Accidents 4yr. 3yr.	Accidents Per Establishment 4yr. 3yr.	Accidents Per Driveway 4yr. 3yr.
231	5	7	1.40	7	.35	.47
232	1	1	1.00	1	.25	.33
241	1	1	1.00	0	.00	.00
242	5	6	1.20	1	.05	.07
243	23	29	1.26	9	.10	.09
311	4	15	3.75	60	3.75	3.09
411	2	2	1.00	0	.00	.00
421	37	37	1.00	5	.03	.03
511	--	88	--	--	--	--
512	16	16	1.00	6	.09	.10
611	1	3	3.00	3	.75	1.00
621	2	5	2.50	8	1.00	1.33
711	9	9	1.00	0	.00	.00
712	5	6	1.20	0	.00	.00

shopping centers were very similar in size and type of shops in them. A 12 hour volume count was taken at one center, and the information was plotted as a graph of hourly volume versus hour of the day. Then, the driveway volume counts for the second shopping center were taken and plotted on the same graph. This is shown in Figure 1. The second count was only a 6 hour count. By making use of the assumptions listed earlier, the second curve was extended, as denoted by the dotted portions of the line in the figure.

In this way, a reasonably reliable volume count was obtained for each establishment in the study sections. Driveway volumes ranged from zero, at several driveways, to over 4900 vehicles per day at a community shopping center. On an establishment basis, volumes ranged from zero to a maximum of 9197 vehicles per day at a large manufacturing plant.

The greatest number of driveway accidents did not occur at the driveway with the greatest volume. There were 35 driveway accidents attributed to a community shopping center, in a four year period. This driveway had an estimated volume of 3080 vehicles per day. Factors affecting this high accident number included the proximity of the driveway to a major intersection, about 300 feet away, and the presence of a major industrial driveway directly across the street. This pair of driveways acted as a major intersection, with a through roadway volume of nearly 16000 (1972) ADT, and driveway volumes of 3080 and 2000 vehicles per day. There were no traffic control devices present. The industrial driveway experienced 20 accidents in the same four year period, and all of them occurred during periods when the work shifts changed.

The 65 most heavily used, of the 434 driveways were chosen in order to analyze directional movements at

FIGURE 1. NEIGHBORHOOD SHOPPING CENTER—DRIVEWAY VOLUME BY HOUR OF DAY

driveway locations. There were 26705 vehicles counted in 344 hours of data collection. This represented an average count of 5.3 hours per driveway. Of the sample, 57.7% of the vehicles made right turns either to or from a driveway, 42.3% made left turns; 30.3% made right turns into driveways, 22.4% made left turns into driveways, 27.4% made right turns out and 19.9% made left turns out. By totalling the in and out percentages, 52.7% went into the driveways while 47.3% left the driveways. The in and out percentages are unequal because some establishments have driveways on more than one street front, and only the driveways located in the study sections were included in the analysis.

Accident Data

During the four year period of the study, there were a total of 1638 traffic accidents recorded on the 14 study sections. Of these, 545 were driveway accidents, or 33.3% of the total number of accidents. This percentage is much higher than that found by either Box (12%) or McGuirk (14%). This was probably due to the nature of the study sections used, that is, congested arterial roadways with a high number of turning movements.

The distribution of driveway accidents by month of year is shown in Figure 2. From the figure, it appears that the spring months were the safest, in terms of driveway accident occurrence, and the fall months were the most dangerous. By grouping the months into quarters of a year, this trend became more pronounced, and is shown in Figure 3. Many of the establishments responding to the questionnaire survey listed the last quarter as their busiest period, reflecting increased driveway movements, which probably explains the higher accident numbers in that period.

FIGURE 2. DRIVEWAY ACCIDENT DISTRIBUTION BY MONTH OF YEAR

FIGURE 3. DRIVEWAY ACCIDENT DISTRIBUTION BY QUARTER OF YEAR

By listing driveway accidents by day of month, no particular trend was discovered, as shown in Figure 4. However, by segregating driveway accidents by day of week, Figure 5, significant factors emerged. The fewest number of driveway accidents occurred on Sunday, when roadway volumes were lowest and few major traffic generators experienced a large business volume. Over three times the number of accidents from Sunday occurred on Friday, when roadway volumes were maximum and most major establishments experienced their greatest business volume.

When driveway accidents were grouped by hour of the day, a curve as in Figure 6 was generated. From this graph, the critical period for driveway accident production was between 3 - 6 p.m., when 173, or 31.8% of the driveway accidents occurred. This corresponds not only to the evening rush hour period but also to the beginning of the peak driveway usage period. The 4th highest hour of driveway accident occurrence was between 12 midnight and 1 a.m. in the morning, when there were 37 accidents. Most of these accidents occurred at industrial driveway which experienced shift changes at that time.

When a plot of average roadway volume was superimposed on the graph of the driveway accidents by hour of the day, two facts became apparent. Although roadway volumes were high in the morning rush hour period, accident rates did not significantly increase in this time period. Most morning driveway movements are movements into only a certain few driveways, and these movements apparently are anticipated by other drivers. As a result of this knowledge, driveway accidents are averted. Secondly, although roadway volumes decreased in the evening, driveway accidents occurred at a generally uniform rate, reflecting fairly continuous use of driveways in the evening shopping period.

FIGURE 4. DRIVEWAY ACCIDENT DISTRIBUTION
BY DAY OF MONTH

FIGURE 5. DRIVEWAY ACCIDENT DISTRIBUTION
BY DAY OF WEEK

FIGURE 6. DRIVEWAY ACCIDENT DISTRIBUTION BY HOUR OF DAY

There were no fatal accidents in the four year period. Of the 545 driveway accidents, 91% involved property damage only, and 9% were personal injury accidents. Of the 9% personal injury accidents, 49% resulted from right angle collisions were 71.4% of those involved a left turn maneuver. This last value was similar to that found by McGuirk, and by Box, in their studies. Sixty three percent of all driveway accidents involved a left turn maneuver.

Vehicles going into driveways caused 53.4% of the accidents, vehicles leaving driveways caused 43.1% of the driveway accidents and a vehicle entering a driveway collided with a vehicle leaving the same driveway 3.5% of the time. Fifty-nine percent of the accidents were listed as being caused by the vehicle using the driveway, 30% were not caused by the driveway vehicle while 11% were undetermined.

Sixty-one percent of the driveway accidents recorded were the result of right angle collisions, while 30% of the accidents were rear end accidents. The other 9% were other types of accidents, including sideswipes and head-on collisions.

Obscured vision, in terms of parked cars, signs, rain, fog, ice and snow were reported to be factors in 15% of the accidents. Sixty-nine percent of all the driveway accidents occurred in the daylight hours, while 31% occurred at night. These figures appear logical due to the fact that very few establishments are open for more than half of the night-time (or darkened) hours.

Seventy-eight percent of the driveway accidents occurred in clear weather conditions, 17% in the rain and 5% in other conditions. However, the pavement condition was dry 70% of the time. There appears to be a tendency for some driveway accidents to occur immediately after some type of precipitation, either from icy patches or

large puddles in the driving lanes, etc. Wet pavement conditions occurred 24% of the time, and icy or snowy conditions 6% of the time.

Land Use and Volume Characteristics

The amount of use an individual driveway received was dependent on several factors. These factors included geometric design, such as width and corner radius; sight restraints; location with respect to parking areas and the building being served; type of land use; and economic stability of the land use. There were instances when all of these factors were important.

Individual driveway volumes to a single establishment or shopping center seemed to vary with respect to the location of its driveways. In the case of one neighborhood shopping center, one driveway carried only 9% of the total daily volume to the center. The other two carried 91% of the volume. The driveway carrying the lowest volume was the farthest from the parking area, and separated from the main shopping area by a series of gasoline pumps.

The type of land use served was extremely important in ranking the volumes recorded. As seen in Table 9 the land uses generating the greatest driveway volumes were all either major shopping facilities or industrial plants. However, relative to the number of accidents that occurred at these driveways, it was found that the greatest number of accidents occurred at the driveway with the third highest volume.

A closer look at the three driveways with the highest volumes explained these findings. The driveway with the highest volume led to a community shopping center. It had an approximately 100 foot long median in the driveway, and left turn and right turn only lanes were provided on the street for ingress to the shopping center. The second

Table 9. Driveways Serving Commercial Land Uses, Ranked According to Volume

Driveway Identification Number	Land Use of Driveway	Driveway Volume	Number of Accidents 3 Years
418	Community Shopping Center	4902	4
98	Neighborhood Shopping Center	3129	2
112	Community Shopping Center	3080	22
6	Neighborhood Shopping Center	2826	9
107	Industrial Plant	2550	4
291	Neighborhood Shopping Center	2370	6
106	Industrial Plant	2100	2
113	Community Shopping Center	2070	3
108	Industrial Plant	2000	12
79	Department Store	1915	7

driveway was 30 feet wide, had no sight restrictions of any kind and was on a relatively low-volume highway. The third driveway was approximately 300 feet from a major highway intersection and there was a high volume industrial driveway directly across the street. There were numerous traffic tie-ups in the area, as the roadway carried a relatively high volume.

In the case of the first two driveways, good geometric design had minimized the accident rate, even with high driveway volumes present.

The size and the economic well-being of an establishment are also important factors affecting driveway volumes. This was especially evident in the dining and carry out restaurant and service station categories. Some of these driveways registered less than 100 vehicles per day, while others registered well over 700 vehicles per day.

In Table 10 driveways are ranked according to the number of accidents recorded in a three year period. If Tables 9 and 10 are compared, only four of the driveways from the first table appear on the second. Of the six other driveways in Table 10, five have volumes of less than 800 vehicles per day.

Of the driveways which carried an average daily driveway volume between 800 and 1800 vehicles none exhibited a high accident rate. This might indicate a region where driveway movements become less random, and more drivers on the roadway become aware of a potential turning movement, thus decreasing the chances of a random driveway accident occurring. Some improvement in the quality of design of driveways above 800 vpd may also have existed.

Studying the plot of driveway accidents per driveway versus driveway volume (Figure 7) it was noted that driveways with volumes between 700 and 800 vehicles per day averaged 6 accidents per driveway for the three year period. At the 2000 to 2100 vehicles per day range,

Table 10. Driveways Serving Commercial Land Uses, Ranked According to Number of Accidents

Driveway Identification Number	Land Use of Driveway	Number of Accidents 3 Years	Driveway Volume
112	Community Shopping Center	22	3080
481	Dining and Carry-Out Restaurant	13	680
108	Industrial Plant	12	2000
82	Dining and Carry-Out Restaurant	12	760
522	Dining and Carry-Out Restaurant	12	500
6	Neighborhood Shopping Center	9	2826
139	Dining and Carry-Out Restaurant	8	750
79	Department Store	7	1915
249	Industrial Plant	7	1800
111	Community Shopping Center	7	770

there was still 6 accidents per driveway over the same period. For this data, then accident rates ranged from about 8 accidents to about 3 accidents per 1000 vehicles daily volume, per three year period.

As shown in Table 10, dining and carry-out restaurants were a major source of driveway accident production. However, several other dining and carry-out restaurant driveways, with similar volumes, had no more than 2 driveway accidents in the same period. One major difference between the two groups included proximity to an intersection. All four of the high-accident driveways served establishments located on the corner of an intersection. In contrast, the restaurants with the lowest driveway accident rates were located in the middle of the block. There were no major differences in geometrics between the corner and mid-block driveways. However, sight distance might have been the determining actor in the driveway accident occurrence, although this could not be easily determined from the accident records available.

By aggregating the data, so that all driveway volumes serving a particular establishment were combined, a similar pattern of driveway volumes and accidents was found. The major difference between the individual driveway data and the establishment data was that there was a more consistent relationship between the volume and accident totals for the establishment data.

Land Use and Accident Rates

In Table 8 the number of accidents per driveway and number of accidents per establishment, for both three and four year accident records, are listed. Community shopping centers experienced the highest accident record by both establishment and driveway totals. The values for neighborhood shopping centers, department stores and

industrial categories were about one-half of the driveway accident number for community shopping centers.

Two groups of land use classifications exhibited interesting accident values. Dining only restaurants had 0.43 driveway accidents per establishment per year, while dining and carry-out restaurants had 0.89. The major difference between the two land use categories was that the driveway volumes for the dining and carry-out restaurants were significantly higher than for the dining only restaurants, at noon and in the evening to just before closing time, usually from 11:00 p.m. till 1:00 a.m.

The second pair of land uses with contrasting accident rates were service stations with and without garage facilities. There were an equal number of accidents for both land use subcategories in the three year period, but there were only half as many establishments in the group without garage facilities. The location of an establishment within a block was similar for each group.

If the average estimated driveway volumes were compared for each group, the volumes at the service stations without garage facilities were nearly twice that of the stations with garage facilities. There were no other factors which were as significant, with respect to driveway accident production, as the variable driveway volume.

Developing a Regression Model for the Data

Much has been said, so far, on the relationship between driveway accident occurrence and several roadway, driveway and land use characteristics. However, the direct relationship has not been determined. This was investigated by use of a multiple regression technique. Regression analysis is particularly useful where many variables are involved.

Since the data was collected in a disaggregated form, three relationships were studied. The three dependent variables are driveway accidents per driveway per year; driveway accidents per establishment per year; and driveway accidents per mile of arterial street per year.

In its basic form the data were used to determine the first dependent variable, driveway accidents per driveway per year. By grouping the driveways according to what establishment they serve, the second dependent variable was determined. The last dependent variable, driveway accidents per mile per year, was obtained by grouping the driveways by study section.

Because of the large number of variables studied, and also the number of driveways involved, a computer program employing a stepwise regression technique was obtained. The stepwise regression technique adds prediction variables, one at a time, to the regression equation. When no additional benefit can be added, by the addition of another variable, to the regression, the procedure is finished. Variables enter the equation in relation to the partial correlation with the dependent variable. The variable with the highest partial correlation enters first. The second variable to enter is the variable with the highest partial correlation, given that the first variable is already in the equation. This process of selection of independent variables continues until either the variable list is exhausted or there are no variables that would add significance to the model.

Regression Analysis at the Driveway Level

The first analysis was performed on the data based on individual driveways. The dependent variable in this case was the driveway accidents per driveway per year. The list of independent variables used in this phase is shown in Table 11.

Table 11. Variables Used in the Driveway Regression Model

Index	Description												
Y_d	Driveway accidents per driveway per year												
X_1	1970 Average Daily Traffic passing on the street in front of the driveway in 1000 vehicles												
X_2	Width of the driveway in feet												
X_3	Dummy Variable - coded 1 for 1-way or 2 for 2-way use of the driveway												
X_4	Average daily volume using the driveway in 1000 vehicles												
X_5, X_6, X_7	Land Use Classification												
	<table><tr><th>Trade X_5</th><th>Service X_6</th><th>Other X_7</th></tr><tr><td>1</td><td>0</td><td>0</td></tr><tr><td>0</td><td>1</td><td>0</td></tr><tr><td>0</td><td>0</td><td>0</td></tr></table>	Trade X_5	Service X_6	Other X_7	1	0	0	0	1	0	0	0	0
Trade X_5	Service X_6	Other X_7											
1	0	0											
0	1	0											
0	0	0											

The stepwise regression, in all cases, was performed so that as many variables as possible could enter the model. However, there generally was a point at which the variables added to the model did not significantly increase the multiple correlation coefficient, R^2 . The value of R^2 ranges from zero to one, and the closer to one, the better the regression model. Also, the fewer the number of variables to be used in the model, the easier it is to maintain and collect data for the model.

In order to determine the significance of the addition of a variable, a test to determine a significant increase in R^2 was conducted after the inclusion of each variable. An F test was used as follows:

$$F = \frac{(R_j^2 - R_k^2) / (j - k)}{(1 - R_j^2) / (n - j - 1)}$$

with $(j - k)$ and $(n - j - 1)$ degrees of freedom

Where

- F - calculated F value
- R_j^2 - multiple correlation coefficient with j independent variables in the model
- R_k^2 - multiple correlation coefficient with k independent variables in the model
- n - total number of observations
- j - number of independent variables in the model to be tested for a significant increase in R^2
- k - number of independent variables in the model to base the significant increase in R^2

The calculated value of F was compared with the F, in a table, with $(j - k)$ and $(n - j - 1)$ degrees of freedom. When the F value from the table exceeded the calculated F, no significant increase in R^2 was experienced by adding that last variable to the model. A significance level of 0.05 was used for the test.

Using all data collected, that is, 434 driveways as data points, the following regression equation to predict driveway accidents per driveway per year was developed.

$$Y_d = -0.17 + 0.77 \text{ (Average Daily Driveway Volume/1000)} \\ + 0.02 \text{ (Average Daily Roadway Volume/1000)}$$

The remaining independent variables produced insignificant improvements in the predictability of the model. The R^2 for this model was only 31.8%.

Attempts to improve the model were made with some success. In addition to the main effect independent variables, all possible two-way multiplicative interactions were added to the regression. Also, the ratio of driveway volume to roadway volume was included. The best model predicted 40.1% of the driveway accidents per driveway per year. The equation involved three independent variables, developed from the two main effect terms, the roadway volume and the driveway volume, and is shown below.

$$Y_d = 0.08 + 0.29 \frac{\text{(Roadway Volume)} \text{ (Driveway Volume)}}{1,000,000} \\ - 5.46 \text{ (Driveway Volume / 1000)} \\ + 28.7 \text{ (Driveway Volume/Roadway Volume)}$$

Where all volumes are average daily volumes. By factoring out the variable (Driveway Volume / 1000), the equation becomes

$$Y_d = 0.09 + \frac{\text{Driveway Vol}}{1000} \left(0.29 \frac{\text{(Roadway Vol)}}{1000} \right) \\ - 5.46 + 28720 / \text{Roadway Volume})$$

Assuming that the variable (Driveway Volume / 1000) a constant, the second term is always positive for all values of Roadway Volume within the limits of the study range, thus indicating that as driveway volume increases, the accident rate per driveway per year increases.

The fact that the R^2 value for this model was low indicated that other factors were important in driveway accident production. The location, or frame of reference

and other factors of the individual driveway should be taken into account in order to incorporate effects external to the driveway itself.

Regression Analysis at the Establishment Level

By grouping the driveways according to the establishment served, data pertaining to accident occurrence by establishment was developed. Variables used to develop the regression equation for establishments are listed in Table 12.

The procedure employed for the regression of the driveway data was also used for this phase, that is, stepwise regression was utilized to predict driveway accidents per establishment per year using main effect terms. There were 277 data points for this regression.

The regression equation using the main effect terms only included two variables.

$$Y_e = -0.34 + 0.90 (\text{Driveway Volume} / 1000) \\ + 0.03 (\text{Roadway Volume} / 1000)$$

Where all volumes are average daily volumes. By including the interaction terms of all of the variables in the regression, the equation became

$$Y_e = 0.12 + 0.23 \frac{(\text{Roadway Vol}) (\text{Driveway Vol})}{1,000,000} \\ - 3.78 (\text{Driveway Volume} / 1000) \\ + 19.39 (\text{Driveway Vol/Roadway Vol})$$

If the variable (Driveway Volume / 1000) is factored out, the equation becomes

$$Y_e = 0.12 + \frac{(\text{Driveway Vol})}{1000} \left(0.23 \frac{\text{Roadway Vol}}{1000} \right. \\ \left. - 3.78 + (19390 / \text{Roadway Vol}) \right)$$

Table 12. Variables Used in the Establishment Regression Model

Index	Description												
Y_e	Driveway Accidents per establishment per year												
X_1	1970 Average Daily Traffic passing on the street in front of the establishment in 1000 vehicles												
X_2	Number of driveways to the establishment												
X_3	Average daily volume using the driveways to the establishment in 1000 vehicles												
X_4, X_5, X_6	Land Use Classification												
	<table><tr><th>Trade X_4</th><th>Service X_5</th><th>Other X_6</th></tr><tr><td>1</td><td>0</td><td>0</td></tr><tr><td>0</td><td>1</td><td>0</td></tr><tr><td>0</td><td>0</td><td>0</td></tr></table>	Trade X_4	Service X_5	Other X_6	1	0	0	0	1	0	0	0	0
Trade X_4	Service X_5	Other X_6											
1	0	0											
0	1	0											
0	0	0											

The R^2 for the first model was 56.4% while the R^2 for the model including interactions was 64%.

The only variables that were significant enough to enter the equations were the same variables used in the regression for driveways. This was the case in both establishment models. Also, the arithmetic signs of each coefficient were the same as the driveway models, and the conclusions were similar. As driveway volumes per establishment rise, the number of accidents per establishment per year rises also, for all ranges of roadway volumes used in the study.

The establishment data was also broken down by land use, in order to test whether an adequate model could be developed for evaluation of certain land use types.

Two classifications were chosen, the General Trade and Service classifications. These two were chosen because most accidents occur at driveways to those land uses, and they generally experienced the highest volumes of traffic movement.

The variables used for these models include those shown in Table 12, with the exception of the land use variables. The best model for each classification proved to be the main effects plus interactions model. The model for the General Trade classification, with 152 data points, was

$$Y_{e_{GT}} = 0.24 + 0.08 \frac{(\text{Roadway Vol}) (\text{Driveway Vol})}{1,000,000} \\ - 10.09 (\text{Driveway Vol} / \text{Roadway Vol}) \\ + 0.21 (\text{Number of Driveways}) \frac{(\text{Drive Vol})}{1000}$$

Where all volumes are average daily volumes Re-arranging terms, the equation became

$$Y_{e_{GT}} = 0.24 + \frac{(\text{Driveway Vol})}{1000} \left(0.08 \frac{\text{Roadway Vol}}{1000} \right. \\ - (1009 / \text{Roadway Volume}) \\ \left. + 0.21 (\text{Number of Driveways}) \right)$$

The R^2 for this model was 57.2%, not as significant as the model involving all types of driveways. However, a new variable entered the equation, the number of driveways per establishment.

The regression equation developed for the Service category, for 52 sample points, was

$$Y_{e_s} = 0.03 + 0.22 \frac{(\text{Roadway Vol}) (\text{Driveway Vol})}{1,000,000} \\ - 1.28 (\text{Driveway Volume} / 1000) \\ - 0.38 \frac{(\text{Number of Driveways}) (\text{Driveway Vol.})}{1000}$$

Where all volumes are average daily volumes. In factored form it became

$$Y_{e_s} = 0.03 + \frac{(\text{Driveway Vol})}{1000} \left(0.22 \frac{(\text{Roadway Vol})}{1000} \right) \\ - 1.28 - 0.38 (\text{Number of Driveways})$$

This equation was able to predict 49.6% of the total variation of the dependent variable. In this model, the ratio of Driveway to Roadway Volume was replaced by the variable Driveway Volume.

For simplicity of interpretation of the models, an example with the number of driveways set equal to one was made. For roadway volumes below approximately 10000 vehicles per day (vpd), the number of accidents for the General Trade category decreased as the driveway volume increased. For volumes greater than 10000, the accidents increased. In the case of the Service category, below approximately 7600 vpd, the driveway accident decreased with increasing driveway volume. Above 7600 vpd they increased.

In summary the establishment model employing all types of land uses, including all interactions between variables was the best model to predict driveway accidents per establishment per year. However, the models restricted to one particular land use should be investigated further to determine their predictability for driveway accidents per establishment per year for their respective land use type.

Regression Analysis at the Section Level

The last type of regression analysis to be performed on the data was on the section level. Since the roadway sections were of variable lengths, all data was standardized to a per mile basis. Any variable, either a roadway or driveway variable, that was suspected of being influential to the production of driveway accidents was included. The variables are listed in Table 13. The dependent variable for this model was driveway accidents per mile per year.

Because there were only 14 roadway sections, or data points, to predict the dependent variable, two steps were taken to ensure that the proper independent variables were chosen for the final regression model. First, each independent variable was plotted against the dependent variable, driveway accidents per mile per year. From this analysis, the relationship between each independent and the dependent variable was studied to determine the significance of the independent variable and whether a linear or another approach was the most feasible.

Through this type of analysis it was found that section 3, State Street, exhibited effects not characteristic of the other 13 sections. One possible cause for this is that there is a two-way-left turn lane present, a feature not found in any of the other sections.

The correlation coefficients of the independent variables were also studied. A list of the important correlation coefficients with respect to the dependent variable is in Table 14. From this analysis it was found that roadway volume and the ratio of medium plus high volume driveways per mile to the total number of driveways per mile were most highly correlated with the dependent variable. It should be noted that the number of low volume driveways

Table 13. Variables Used in the Section Regression Model

Index	Description
Y_s	Driveway accidents per mile per year
X_1	1970 population
X_2	1970 Average Daily Traffic passing on the roadway in 1000 vehicles
X_3	Average daily driveway volume per section in vehicles per day
X_4	Average driveway volume per driveway per section in vehicles per day
X_5	Average daily driveway volume per mile in 1000 vehicles per day
X_6	Roadway speed limit in miles per hour
X_7	Width of the traveling portion of the roadway in feet
X_8	Number of through lanes on the roadway
X_9	Traffic signals per mile
X_{10}	Alleys per mile
X_{11}	Three-way intersections per mile
X_{12}	Four-way intersections per mile
X_{13}	Total intersections per mile
X_{14}	Number of low volume driveways per mile (less than 250 vehicles per day)
X_{15}	Number of medium volume driveways per mile (between 250 and 800 vehicles per day)
X_{16}	Number of high volume driveways per mile (greater than 800 vehicles per day)

Table 13. (Continued)

Index	Description
X ₁₇	Total number of driveways per mile
X ₁₈	Average width of the driveways per section in feet
X ₁₉	Total number of curb-cuts per mile
X ₂₀	Number of driveways per establishment per section
X ₂₁	Number of establishments per mile with low volume driveways (less than 375 vehicles per day)
X ₂₂	Number of establishments per mile with medium volume driveways (between 375 and 1200 vehicles per day)
X ₂₃	Number of establishments per mile with high volume driveways (greater than 1200 vehicles per day)
X ₂₄	Number of establishments per mile
X ₂₅	Observed driveway volume, % right turn
X ₂₆	Observed driveway volume, % left turn
X ₂₇	Observed driveway volume, % in - right
X ₂₈	Observed driveway volume, % in - left
X ₂₉	Observed driveway volume, % out - right
X ₃₀	Observed driveway volume, % out - left
X ₃₁	Observed driveway volume, % in
X ₃₂	Observed driveway volume, % out

Table 13. (Continued)

Index	Description
X_{33}	(Number of medium and high volume driveways per mile divided by the total number of driveways per mile) (100)
X_{34}	Number of medium volume driveways per mile plus the number of high volume driveways per mile

Table 14. Coefficient Correlations of Specific Independent Variables with Respect to the Dependent Variable

X ₂	Average daily traffic passing on roadway in 1000 vehicles	0.70439
X ₅	Average daily driveway volume per mile in 1000 vehicles per day	0.17732
X ₄	Average driveway volume per driveway per section in vehicles per day	0.31922
X ₇	Width of traveling portion of roadway in feet	0.44932
X ₁₈	Average width of driveway per section in feet	0.37407
X ₂₀	Number of driveways per establishment per section	0.52193
X ₁₄	Number of low volume driveways per mile (less than 250 vehicles per day)	-0.16321
X ₁₅	Number of medium volume driveways per mile (between 250 and 800 vehicles per day)	0.41792
X ₁₆	Number of high volume driveways per mile (greater than 800 vehicles per day)	0.16923
X ₁₇	Total number of driveways per mile	0.00186
X ₃₃	Number of medium and high volume driveways per mile divided by total number of driveways per mile (100)	0.50035
X ₃₄	Number of medium plus high volume driveways per mile	0.35576

per mile and the total number of driveways per mile (most of which were low volume) were poorly correlated with the dependent variable, the most acceptable regression model developed from the 13 study sections was able to predict 83.3% of the variability of the dependent variable. It is

$$Y_s = -2.81 + 1.53 \frac{(\text{Roadway ADT})}{1000} + 0.41 \frac{(\text{No. of Medium + High Vol Driveways})}{\text{Number of Driveways per Mile}} (100) - 0.54 \frac{(\text{Average Daily Driveway Vol per mile})}{1000}$$

The only data which need to be collected for input to this model are the roadway ADT, the driveway volume for each of the driveways located on the section of highway, and the number of driveways on that study section. By grouping the driveways according to volume, the second variable can be developed.

It is important to note that this regression equation, as all similarly developed ones, must be viewed in total and that individual independent variables cannot be analyzed separately by the model. This equation does not state, for example, that an increase in average driveway volumes per mile will decrease accidents. It states that a certain ADT and a certain medium plus high volume driveway ratio and a certain driveway volume per mile will likely result in a certain number of accidents. Relative to each of the independent variables, it states nothing else.

Modification of the Section Model

If a condition existed where there were no vehicles on the arterial highway or using the driveways on that section, there should be no driveway accidents. By assuming this situation to exist, a regression employing the same variables was performed. This model has an R^2 of 82.6%, and is

$$\begin{aligned}
 Y_s = & 1.38 \frac{(\text{Roadway ADT})}{1000} \\
 & + 0.42 \frac{(\text{No. of Med. \& High Vol. Driveways/Mile}) (100)}{\text{Number of Total driveways per mile}} \\
 & - 0.58 \frac{(\text{Average Daily Volume per Mile})}{1000}
 \end{aligned}$$

The constants for each variable changed only slightly from the first model. Since the degrees of freedom are small in both cases, by assuming an origin of zero for the model, an additional degree of freedom is added to the residual, thus decreasing the mean square value. Even with a decrease in the R^2 from 83.3% to 82.6%, it was felt that, due to the small sample size, the model with the origin through zero was the most satisfactory for the data.

Testing the Section Model

A test of the model was accomplished by using the model to predict the number of driveway accidents per mile for the year 1972. The R^2 for the test of the model was 63%. This value was less than the R^2 for the actual model, and probably is the result of an inadequate time period to determine the dependent variable. A more valid test would be to use a three year period of driveway accident records (as used for the model development) instead of a one year period.

Restrictions to the Regression Models

A regression model, developed by utilizing field data, should only be used to predict the dependent variable using values of the independent variables that are within the range of values of the independent variables used when developing the model.

The ranges of independent variables for the driveway establishment and section regressions are shown in Table 15. If these models are to be used to predict driveway accidents per unit, the independent variables must stay within the ranges listed in the table. The variables, however, do represent a fairly wide range of values when compared to a typical arterial highway.

Table 15. Range of Significant Variables

Variable	Maximum	Minimum	Range
Driveway Model			
Driveway accidents per driveway per year	7.33	0.0	7.35
Roadway ADT	19832	6487	13345
Driveway volume per driveway in vehicles per day	4902	0	4902
Establishment Model			
Driveway accidents per establishment per year	10.67	0	10.67
Roadway ADT	19832	6487	13345
Driveway volume per establishment in vehicles per day	9197	0	9197
Section Model			
Driveway accidents per mile per year	42.77	9.04	33.73
Roadway ADT	19832	6487	13345
Average daily driveway volume per mile in vehicles per day	39000	3600	35400
Medium plus high volume driveways per mile divided by total driveways per mile	.56	.06	0.50

SUMMARY OF RESULTS

The important results of this research project cover many areas. The questionnaire passed out to the store managers reported that Friday is the busiest day of the week for their businesses.

From the driveway accident records, Friday is also the day of the week with most driveway accidents.

Driveway volumes studied ranged from zero to over 4900 per day. On an establishment basis driveway volumes ranged from zero to nearly 9200 vehicles per day.

From a sample of 344 hours of driveway volume counts, 26,705 vehicles were counted. Of that total 57.7% made right turns, 42.3% made left turns; 30.3% turned in-right, 22.4% turned in-left, 27.4% turned out-right and 19.9% made out-left turns; 52.7% went into the drives while 47.3% left the driveways. The in and out movements were not equal due to establishments located on the study sections that were served by additional driveways on other streets.

One-third of the 1638 traffic accidents on the 14 study sections were driveway accidents.

The last three months of the year experienced more driveway accidents than any other quarter. The second quarter had the fewest number of driveway accidents.

By classifying driveway accidents by hour of the day, 173, or 31.8%, of the driveway accidents occurred between the hours of 3-6 p.m. The fourth highest hour of driveway accident production was between 12 and 1 a.m. in the morning, when 37 driveway accidents occurred in a four year period.

Of the 545 driveway accidents, 91% resulted in only property damage, while 9% involved some type of personal injury. There were no fatal injury driveway accidents during the four year period.

Left turns were involved in 63% of the driveway accidents, and 71.4% of the personal injury accidents included a left turn maneuver.

Vehicles going into driveways caused 53.4% of the driveway accidents, vehicles leaving driveways caused 43.1% of the driveway accidents and a vehicle entering a driveway collided with a vehicle leaving the same driveway 3.5% of the time. Right angle accidents constituted 61% of the total accidents.

Obscured vision was a factor in 15% of the driveway accidents. Two-thirds of the accidents occurred in daylight, and 78% of the accidents were recorded in clear weather. Seventy percent of the time the pavement was dry.

Driveway volume depended upon many factors, including type and intensity of land use. Economic stability and location of store area with respect to the driveway were also important factors.

Driveways serving shopping centers and industrial plants usually had the highest driveway volumes. However, the greatest number of accidents occurred at shopping center, industrial and dining and carry-out restaurant driveways.

Community shopping centers experienced an average of about 6 driveway accidents per establishment per year for a three year period. Neighborhood shopping centers and department stores had 3.34 driveway accidents per establishment per year.

Driveways to dining and carry-out restaurants had 0.90 driveway accidents per establishment per year, while eat-in restaurants had 0.43 driveway accidents per establishment per year.

Service stations with garage facilities had accident totals half that of service stations without garages. The latter category, however, had driveway volumes twice that of the former.

Stepwise regression analysis was used to develop a model to predict driveway accidents per driveway per year. The best model developed for this purpose was

$$y_d = 0.09 + 0.29 \frac{(\text{Roadway Volume})(\text{Driveway Volume})}{1,000,000} \\ - 5.46 \frac{(\text{Driveway Volume})}{1000} \\ + 28.72 (\text{Driveway Volume}/\text{Roadway Volume})$$

where all volumes are in average number of vehicles per day.

The model developed to predict the number of driveway accidents per establishment per year was

$$y_e = 0.12 + 0.23 \frac{(\text{Roadway Volume})(\text{Driveway Volume})}{1,000,000} \\ - 3.78 \frac{(\text{Driveway Volume})}{1000} \\ + 19.39 (\text{Driveway Volume}/\text{Roadway Volume})$$

Where all volumes are in average number of vehicles per day.

Models were also developed to predict the number of driveway accidents per establishment per year for land use classifications of General Trade and Service. However, the general model was judged to be superior to the two more specific models.

Due to the fact that one of the study sections exhibited characteristics very dissimilar to the remaining sections, the regression for roadway sections was performed using only 13 of the 14 available sections. Also, after further study and tests, it was determined that the best model occurred when the regression line was forced through the zero origin. Driveway accidents per mile per year were best predicted by the model

$$\begin{aligned}
 Y_s = & 1.38 \left(\frac{\text{Roadway ADT}}{1000} \right) \\
 & + 0.42 \left(\frac{\text{No. of Med. + High Vol. Driveways/Mi.}}{\text{Total Driveways Per Mile}} \right) (100) \\
 & - 0.58 \left(\frac{\text{Average daily driveway Volume per Mile}}{1000} \right)
 \end{aligned}$$

The R^2 for this model was 82.6%.

CONCLUSIONS

After reviewing the data, several conclusions were made concerning the driveway accidents included in this study.

1. Driveway accidents were found to represent one-third of all traffic accidents on those sections of arterial highways serving commercial land uses.
2. The number of driveway accidents tended to increase considerably between driveway volumes of 250 and 800 vpd. Above 800 vpd driveway volumes, the number of driveway accidents was often less than at lower volumes or increased more slowly with increasing driveway volumes. Two reasons for this decrease at high driveway volumes were noted. First, each high volume driveway often were better designed for safe entrance and exit, and secondly at such driveway volumes, entering or exiting vehicles were almost constantly visible to drivers on the roadway and access maneuvers came as a surprise to very few motorists.
3. Shopping centers, large industrial plants and large dining and carry-out restaurants generated the highest number of driveway accidents. However, driveway volumes at the shopping centers and industrial plants were significantly higher than the driveway volumes at the dining and carry-out restaurants.
4. In terms of accidents per 1000 driveway vehicles, accident rates at driveways with high volumes were lower than accident rates at low or medium volume driveways.

5. In terms of accidents per establishment, community shopping centers had the highest numbers, followed by industrial plants, neighborhood shopping centers and department stores.
6. Driveway accident production was as high or higher from late afternoon into the late evening than any other times of the day.
7. By using data at the driveway level it was found that roadway and driveway volumes were the most significant factors in predicting the number of driveway accidents per year.
8. By using data grouped by establishment it was found that driveway accident occurrence was also primarily dependent upon roadway and driveway volumes. This model was slightly better than the model for driveway accident rates in terms of predictability of the respective dependent variable.
9. The number of driveway accidents per mile per year for sections of fully developed highly commercial (90-100%) arterial highway was dependent on the roadway ADT, the ratio of medium plus high driveways per mile divided by the total number of driveways per mile, and the average daily driveway volume per mile.
10. The section regression model which predicts driveway accidents per mile for sections of fully developed highly commercial arterial highways serving commercial land uses provides the engineer with a model that when used within the boundary ranges from which it was developed will
 - a. predict future driveway accident rates on such sections
 - b. provide accident benefits which would occur from the reduction of the number of medium and high volume driveways on such a highway.

RECOMMENDATIONS FOR FURTHER RESEARCH

Through the course of this research study, many additional areas were identified that require further study to more fully solve the problem of driveway accident occurrence. They are listed below:

1. The models developed with the driveway and establishment data utilized all driveways and establishments located on specific sections of arterial highway. By selecting driveways independent of location, a set of establishments based on one of the land use classification categories or subcategories in this report could be collected, and a model that would adequately predict driveway accidents per driveway (or establishment) per year for that land use category or subcategory might be developed.
2. The effect of driveway design, including one-way operation and separate turn lanes for access vehicles, as well as location of the driveway with respect to other driveways or intersections, on driveway accidents should be evaluated and included as variables in driveway accident models if found to be important. Few one-way driveways and separate turn lanes or other high-type design characteristics existed on the driveways used in this study. The few that had a high-type design exhibited lower numbers of accidents. The nearness of a driveway to other driveways and to an intersection also appeared to be a factor but

data on this factor were not obtained. Another factor which was not evaluated but which appeared to be important at a few sites was obstructions to visibility (signs, hedges, buildings, etc). This factor too should be evaluated.

3. The models developed should be either tested outside the study area involved, or they should be tested with a three year average of driveway accident data on the same study sections.
4. An actual demonstration project to reduce the number of medium and high volume driveways along a section of highway serving commercial land uses should be implemented so that monitoring of all independent variables, before and after, can be conducted. Monitoring of all types of traffic accidents on the study section should also be done to ascertain the effect on each type of accident on the section.

BIBLIOGRAPHY

BIBLIOGRAPHY

1. American Association of State Highway Officials, "An Information Guide for Preparing Private Driveway Regulations for Major Highways", Washington, D. C., 1960.
2. Anaya, M., "Driveways and Approaches for Modern Automobiles", Proceedings of the 9th California Street and Highway Conference, University of California, Berkeley, 1957, pp. 82-91.
3. Billion, C. E. and Parsons, N. C., "Median Accident Study-Long Island, New York", Highway Research Board Bulletin 308, 1962, pp. 64-79.
4. Billion, C. E. and Scheinbart, I., "A Study of Ingress and Egress at Gasoline Service Stations on Rural State Highways Without Control of Access", Proceedings of the Highway Research Board, 1956, pp. 618-660.
5. Blensly, R. C. and Head, J. A., "Statistical Determination of Effect of Paved Shoulder Width on Traffic Accident Frequency", Highway Research Board Bulletin 240, 1960, pp. 1-23.
6. Box, P. C., "Access Control and Accident Reduction", Municipal Signal Engineer, May-June 1965, pp. 27-30.
7. Box, P. C., "Driveways", Traffic Control and Roadway Elements - Their Relationship to Highway Safety, Highway Users Federation for Safety and Mobility, 1970.
8. Box, P. C., "Driveway Accident and Volume Studies (3 parts)", Public Safety Systems, May-June, 1969, pp. 18-22, July-August, 1969, pp. 15-18, September-October, 1969, pp. 16-19.
9. Box, P. C., "Driveway Accident Studies, Major Traffic Routes, Skokie, Illinois", July, 1967, unpublished.
10. Box, P. C., "Signal Control of High Volume Driveways", Municipal Signal Engineer, November-December, 1965, pp. 21-24.

11. Bruggeman, J. M., "Accident Investigation on Rural Expressways", Student Thesis, Civil Engineering Department, Northwestern University, Evanston, Illinois, 1968.
12. Burr, I. W., and Foster, Louis A., "A Test for Equality of Variances", Department of Statistics, Purdue University, West Lafayette, Indiana, 1972.
13. Community Builders' Handbook, Urban Land Institute, Washington, D. C., 1968.
14. Cribbins, P. D., "Correlation of Accident Rates with Geometric Design Components of Various Types of Highways", Final Report ERD-110-0, Engineering Research Department, North Carolina State University, Raleigh, 1964.
15. Cribbins, P. D., Horn, J. W., Beeson, F. V. and Taylor, R. D., "Median Openings an Divided Highways: Their Effect on Accident Rates and Level of Service", Highway Research Board Record 188, 1967, pp. 140-157.
16. Division of Traffic Engineers, Mass Transportation Authority of Greater Indianapolis, "Access Control Manual", January, 1969.
17. Draper, N. R., and Smith, H., Applied Regression Analysis, John Wiley and Sons, 1966.
18. Gwynn, D. W., "Accident Rates and Control of Access", Traffic Engineering, November, 1966, pp. 18-21.
19. Head, J. A., "Predicting Traffic Accidents from Roadway Elements on Urban Extensions of State Highways", Highway Research Board Bulletin 208, 1959, pp. 45-63.
20. Kihlberg, J. K. and Tharp, K. J., "Accident Rates as Related to Design Elements of Rural Highways", National Cooperative Highway Research Project No. 47, Highway Research Board, Washington, D. C., 1968.
21. Marks, H. and Spitz, S., "A Review of Transportation Aspects of Land Use Control", National Cooperative Highway Research Project No. 31, Highway Research Board, Washington, D. C., 1966.
22. Matson, T., Smith, W., and Hurd, F., Traffic Engineering, McGraw-Hill Book Company, Inc., 1955.

23. May, J. F., "A Determination of an Accident Prone Location", Traffic Engineering, February, 1964, pp. 25-28, 56.
24. McDonald, J. W., "Relation Between Number of Accidents and Traffic Volume at Divided Highway Intersections", Highway Research Board Bulletin 74, 1953, pp. 7-17.
25. McGuirk, W. M., "Evaluation of Factors Influencing Driveway Accidents", Joint Highway Research Project C-36-59P, Purdue University, West Lafayette, Indiana, 1973.
26. McReynolds, M. B., and Hanna, J. T., "Driveway Control in Richmond, Virginia", Traffic Engineering, October, 1950, pp. 11-12.
27. Mulinazzi, T. E., "Correlation of Design Characteristics and Operational Controls with Accident Rates on Urban Arterials", Joint Highway Research Project C-36-59H, Purdue University, West Lafayette, Indiana, 1966.
28. Musick, J. V., "Effect of Pavement Edge Marking on Two-Lane Rural State Highways in Ohio", Highway Research Board Bulletin 266, 1960, pp. 1-7.
29. Netherton, R. D., Control of Highway Access, The University of Wisconsin Press, Madison, 1963.
30. Ostle, B., Statistics in Research, Second Edition, The Iowa State University Press, Ames, Iowa, 1972.
31. Peterson, A. O. and Michael, H. L., "An Analysis of Traffic Accidents on a High Volume Highway", Engineering Reprints - No. 225, Purdue University, West Lafayette, Indiana, August, 1966.
32. Petty, D. F. and Michael, H. L., "An Analysis of Traffic Accidents on County Roads", County Highway Series - No. 5, Purdue University, West Lafayette, Indiana, December, 1962.
33. "Protection of Highway Utility", National Cooperative Highway Research Project No. 121, Highway Research Board, Washington, D. C., 1971.
34. Raff, M. S., "Interstate Highway Accident Study", Highway Research Board Bulletin 74, 1953, pp. 18-45.
35. "Recommended Practice Guidelines for Driveway Design and Location", Final Report ITE Committee 5 N-S (67), February, 1972.

36. Recommended Practice for Sub-Division Streets", Traffic Engineering, January, 1967, pp. 15.
37. Schoppert, D. W., "Predicting Traffic Accidents from Roadway Elements of Rural Two-Lane Highways with Gravel Shoulders", Highway Research Board Bulletin 158, 1957, pp. 4-26.
38. Shaw, R. B., "Evaluation of Delays and Accidents at Intersections to Warrant Construction of a Median Lane", Joint Highway Research Project C-36-17EE, Purdue University, 1966.
39. Staffeld, P. R., "Accidents Related to Access Points and Advertising Signs in Study", Traffic Quarterly, January, 1953, pp. 59-74.
40. "Standard Land Use Coding Manual", U. S. Government Printing Office, Washington, D. C., 1965.
41. Stover, V. G., "Regulation of Access Along Arterials", Texas Transportation Researcher, Texas Transportation Institute, October, 1969.
42. Stover, V. G., "Guidelines for Medial and Marginal Access Control of Major Roadways", National Cooperative Highway Research Project No. 93, Washington, D. C., 1970.
43. Traffic Engineering Handbook, Institute of Traffic Engineers, Washington, D. C., 1965.
44. Webb, G. M., "The Relation Between Accidents and Traffic Volume at Signalized Intersections", ITE Proceedings (1955) Session 3B, pp. 149-167.
45. Woo, J. C. H., "Correlation of Accident Rates and Roadway Factors", Joint Highway Research Project, Final Report, Purdue University, West Lafayette, Indiana, 1957.

APPENDIX

Sample FormROADWAY DATA

Section Number _____

Urban Area Pop. _____ City _____

Street # at Terminals NE ____ SW ____ Section Name _____

Section Length ____ft. ____mi. Section Terminals _____ to
_____Traffic Data

Speed Limit ____ MPH

Average Daily Traffic Volume:

1969 _____

1970 _____

1971 _____

1972 _____

Terminal Conditions

N E Terminal

Intersection _____

Other _____

S W Terminal

Intersection _____

Other _____

Traffic Control

N E _____

S W _____

Section Data

One-way ____ Two-way ____ Operation

North-South ____ East-West ____ Direction

Parking:

None ____ Both sides ____ one side ____

NESW

Restrictions _____

Type (parallel, etc.) _____

Width _____ft.

Number thru lanes NE ____;ft.ea.

SW ____;ft.ea.

Lane Marking Yes ____ No ____

Pavement surface type _____

Condition _____

Curbs

None ____ Both sides ____ One side ____

NESW

Sidewalks

None ____ Both sides ____ One side ____

NESW

Shoulders

None

Both sides ____;ft. ea.

One side NESW ____ft. ea.

Sample Form

DRIVEWAY-LAND USE DATA

Code (3-alley, 4-street, 1-res, 2-comm) _____ Section _____

N E S W side of street City _____

Total # Drives to Estab. _____ Section Name _____

Driveway Code Number _____

Name of Driveway User _____

Address _____

Description of Firm:

Description of DrivewaySignalization

Type (grav., etc.) _____

Width _____

One-Way _____ Two-Way _____

Lanes _____

Median _____

Right Turn Lane From Street _____ Right Turn Signal _____

Left Turn Lane From Street _____ Left Turn Signal _____

PLAN VIEW OF DRIVEWAYCOMMENT

Code _____

Number _____

Land Use Code _____

Sample Form

DRIVEWAY ACCIDENT DATA SHEET

Section # _____

Accident # _____

Time of Accident

Date _____
 Day of Week _____
 Time of Day _____ A.M.
 _____ P.M.

Land Use

Commercial _____
 Residential _____
 Other _____

Location

City _____
 Section Name _____; from _____ to _____
 Accident at 1) _____
 2) _____ feet N E S W of intersection with _____
 Driveway Code Number _____

Accident Severity

Fatality _____
 Personal Injury _____
 Property Damage _____

Accident Type

Rear End _____ Head-On _____
 Right Angle _____ Sideswipe _____
 Other _____

CommentPrevailing Conditions

<u>Lighting</u>	<u>Pavement</u>
Daylight _____	Dry _____
Dark _____	Wet _____
Dawn _____	Snow-Ice _____
Dusk _____	Other _____
<u>Weather</u>	<u>Alignment</u>
Clear _____	Straight _____
Rain _____	Curve _____
Fog _____	Level _____
Snow _____	On Grade _____
Other _____	Hillcrest _____

Accident Cause

- 1) Vision Obscured
 Yes _____ By _____
 No _____
- 2) Vehicle Defect
 Yes _____
 No _____
- 3) Other _____
- 4) One Vehicle Going to _____
 from _____ the Driveway
- 5) Vehicle Causing Accident
 was _____ was not _____ un-
 certain _____ involved in
 driveway maneuver

Sample Questionnaire

DRIVEWAY VOLUME INFORMATION

1. Has this business been located here for more than 4 years? _____
If not how long _____
2. Have the number of customers increased or decreased over the past 4 years _____ how much _____
1 year _____ how much _____
3. What is the busiest month of the year? _____
Is _____ an above, below or average month. How much above or below _____
4. Place a 1 next to the busiest week of _____, a 2 next to the second busiest week, etc.
1st _____
2nd _____
3rd _____
4th _____
5. Place a 1 next to the busiest day of the week, a 2 next to the second busiest day, etc.
Sunday _____ Thursday _____
Monday _____ Friday _____
Tuesday _____ Saturday _____
Wednesday _____
6. What are the busiest hours of the day?
7. Is morning, afternoon or evening the busiest period of the day?
8. What is the size of this property (acres, sq. ft., etc.) _____
9. What were your average hours of operation during the past year?

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