EVALUATION OF FACTORS INFLUENCING DRIVEWAY ACCIDENTS

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BY

WILLIAM W. McGUIRK

JHRP

JOINT HIGHWAY RESEARCH PROJECT
PURDUE UNIVERSITY AND
INDIANA STATE HIGHWAY COMMISSION

Interim Report

EVALUATION OF FACTORS INFLUENCING DRIVEWAY ACCIDENTS

TO: J. F. McLaughlin, Director
Joint Highway Research Project
May 3, 1973
File: 8-5-16
FROM: H. L. Michael, Associate Director
Joint Highway Research Project
Project: C-36-59P

Mr. William W. McGuirk, Graduate Assistant in Research on our staff, has prepared the attached Interim Report on the research in progress on "Evaluation of Factors Influencing Driveway Accidents". He also used the Report as his thesis for the MSCE degree. Professor G. T. Satterly, Jr., directed the research.

The purpose of the research is to evaluate the relationship of driveway accidents on urban arterial highways to total accidents and the factors associated with driveway accidents. Driveway accidents were found to be a significant portion of total accidents with left-turn movements to or from a driveway constituting a factor in a large percentage of the accidents. Several models of the relationship of driveway accidents to the characteristics of the roadway and adjacent development were developed. Major factors resulting in driveway accidents were found to be the number of commercial driveways, number of through lanes, number of intersections, number of driveways per mile and traffic volume.

Research on this study is continuing to evaluate factors on several types of highways - one-way, two-way, rural, urban, etc. These will be reported in a subsequent Final Report.

The Interim Report is presented to the Board for acceptance as partial fulfillment of the objectives of the Study.

Respectfully submitted,

Harold L. Michael
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Associate Director

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by

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File: 8-5-16

Project: C-36-59P

Joint Highway Research Project
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In cooperation With
Indiana State Highway Commission

Purdue University
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ABSTRACT

McGuirk, William Walter. M.S.C.E., Purdue University, May 1973. EVALUATION OF FACTORS INFLUENCING DRIVEWAY ACCIDENTS. Major Professor: Gilbert T. Satterly, Jr.

This research study was undertaken to examine the significance of driveway accidents on urban arterial highways, to examine the relationship between the driveway accident rate and the average spacing between adjacent driveways and between a driveway and an adjacent intersection leg, and to reveal those characteristics of the roadway and its abutting environment having the most significant effect upon the driveway accident rate. The overall objective was to disclose the factors which, when properly employed, will serve to effect a significant reduction in the driveway accident rate.

Data relative to roadway characteristics, traffic volume, and driveway accident occurrence were collected from ten central Indiana cities for one hundred segments of arterial street. Accident records for each of the arterial sections were examined over a four year period, from January 1, 1968 to December 31, 1971, so as to provide a three year accident history on which to base the computation of driveway accident rates for analysis purposes and a one year accident history to be used for purposes of testing the results.

Driveway accidents were found to represent a significant percentage, 13.95%, of the total traffic accidents on all one hundred roadway sections over a four year period. Left turn movements, to or from a driveway, resulted in 64.60% of all driveway accidents, and 76.00% of all driveway accidents resulting in personal injury involved a left turn maneuver.

There exists a trend in which the driveway accident rate is found to decrease when the average spacing over a section of roadway between adjacent driveways and between a driveway and an adjacent intersection leg increases.

Stepwise regression analysis was employed to relate the driveway accident rate to roadway characteristics. Preliminary analysis revealed the roadway characteristics to be significantly better correlated to the annual number of driveway accidents per mile rather than to the number of driveway accidents per one hundred million vehicle miles. After discovering that interaction terms were more significant in the prediction of the number of driveway accidents per mile per year than the main effect terms, a model was developed employing six independent variables, arranged by themselves and in combination with each other to form fifteen terms. This model explains 84.52% of the variation in the number of driveway accidents per mile per year.

This study found that the number of driveway accidents per mile per year decreased when the number of commercial

driveways per mile was reduced; when the number of through traffic lanes on the arterial highway was reduced; when the number of total intersections per mile was increased; when the number of total driveways per mile was reduced; when the traffic volume on the arterial highway was reduced; and when the urban area population was increased.

Although the scope of this study was limited to the study of one hundred arterial highway sections in central Indiana, the findings should be of considerable value throughout Indiana and the nation.

INTRODUCTION

The reduction of traffic accidents throughout the world is, and always will continue to be, one of the primary objectives of the highway engineer. His quest for this goal was substantially realized with the introduction of the concept of full control of access, "...the most important single factor in accident reduction ever developed" (29).^{*} Research substantiates this claim. One study made on urban highways disclosed a 65% reduction in accidents following the addition of full control of access on highways where such did not previously exist (28). However, the highway engineer is unable to employ full control of access as a sole solution to the problem of accident reduction as "any complete street and highway system must provide the functions of both land access and traffic movement" (68). The problem of accident reduction is complicated on those facilities where land access and traffic movement must be simultaneously coordinated without delegating an advantage to either function. A case in point is the urban arterial highway which, by nature of its role in the urban transportation system, must encourage

^{*}Numbers in parentheses refer to articles listed in the Bibliography.

efficient through traffic movement while providing access possibilities for abutting landowners. This study will focus upon accident reduction on such facilities where full control of access cannot be considered feasible.

"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 expenditure of their public highway funds" (1). The courts have been forced to settle many arguments resulting from this conflict between the road user and the abutting landowner, and their decisions have defined the basis for many accepted access control practices and standards. The New Hampshire Court, in the 1931 case of Town of Tilden vs. Sharpe (22), stated:

...the test of reasonableness of the proposed use is to be found not by inquiring whether such use is essential to the profitable transaction of any particular business on his lot, but in answer to the inquiry whether such use would be fraught with such unusual hazard that the danger to the traveling public would be out of proportion to the detriment of the owner by being deprived of it...

Likewise, the Pennsylvania Court, in the 1938 case of Brenig vs. Allegheny County (23), concluded:

The absolute prohibition of driveways to an abutting owner's land, which fronts on a single thoroughfare and which cannot be reached by any other means, is unlawful and will not be sustained. But the public authorities have the undoubted right to regulate the manner of the use of driveways by adopting such rules and regulations, in the interest of public safety, as will accord some measure of access, and yet permit public travel with a minimum of danger. The rules

and regulations must be reasonable, striking a balance between the public and private interest. The abutter cannot make a business of his right of access in derogation of the right of the traveling public. He is entitled to make only such use of his right of access as is consonant with traffic conditions and police requirements that are reasonable and uniform.

These two cases, representative of the many decisions rendered in the access conflict, confirm the abutter's legal right to access while, at the same time, reserving the right of the State to control the location, width, and nature of any access point based primarily on the safety of the riding public, and not on the convenience of the abutting property owner. In the eyes of the court, therefore, the conflict still exists, but its ultimate settlement is transferred to the jurisdiction of the highway engineer, and it is through access control policies that the conflict is resolved.

As access is permitted from a parcel of land to the arterial highway by means of a driveway, additional conflicts to the through arterial traffic are introduced. As the number of conflict points along an arterial highway increases, the opportunity for driveway related traffic accidents increases. A driveway accident is defined as a traffic accident in which at least one of the participants was involved in a movement to or from a driveway at the time of an accident, or an accident resulting from such a movement. While many may not receive much publicity, as they often are not spectacular and they do not occur as frequently as the more familiar intersectional accident, driveway accidents do

represent a significant percentage of total arterial highway traffic accidents. A recent study made in Skokie, Illinois revealed driveway accidents to represent 12% of that city's major street accidents (13). Since there is little reason to doubt that this percentage is representative of urban arterial accident experience throughout the country, research directed toward a better understanding of the factors affecting the number of driveway accidents on urban arterial highways would be of great benefit.

LITERATURE REVIEW

One of the earliest attempts to compile a literature review on the subject of driveways and driveway accidents was made in 1970 by Paul C. Box and Associates, sponsored by the Highway Users Federation for Safety and Mobility (11). Aside from the data, tables, and figures presented in the text, the publication lists an excellent bibliography relating to all aspects of driveways and driveway accidents.

Driveway Accident Studies

Although limited in number, driveway accident studies have contributed much toward emphasizing the magnitude of the driveway accident problem. Box discovered driveway accidents to represent 12% of all major street accidents in Skokie, Illinois (13), while Marconi's study in San Francisco, California indicated that driveway accidents represented only 1.3% of all 1964 traffic accidents (43). However, the latter study considered all city streets including local and arterial streets, and it did not include accidents in which the driveway vehicle was not struck, or was struck while waiting to make a maneuver to or from a driveway. It is obvious that the San Francisco rate is biased with respect to the theme of this report, and that the results of the Skokie study are more representative of the actual percentage.

While right turns were found to comprise a majority of the driveway ingress and egress movements at service stations, left turn movements were found to result in more driveway accidents than right turn movements (6). A more recent study by Box, taking into account sections of arterial highway consisting of many different types of driveways, disclosed that 60% of driveway accidents involved a left turn maneuver. Perhaps of greater importance is the fact that left turn accidents accounted for 75% of all injury producing driveway accidents (13). While these figures are indeed significant, it must be remembered that left turning vehicles are in conflict with all vehicles in the opposite direction of flow and a substantial number of vehicles in the same direction of flow, while right turning vehicles are in conflict only with a substantial number of vehicles in the same direction of flow.

Box found driveway accident rates at commercial driveways to increase as the volume of vehicles using that type of driveway increased. In the same publication he indicated those elements which should be evaluated in performing a thorough analysis of a driveway hazard as being the traffic volume on the arterial highway, the number of through traffic lanes, parking conditions, the spacing between driveways and adjacent signalized intersections, and the volume of traffic using the driveway. His studies also uncovered a definite trend toward higher driveway accident

rates with higher major street ADT (12). In another study, Box found the residential driveway accident rate to be very low along major streets, with the rate at commercial driveways being 10 times the rate at residential driveways. This same study uncovered no significant relationship between the number of driveway accidents per mile and the number of openings per mile, or the arterial highway street width (13). Bruggeman utilized statistical analysis to discover driveway accidents to be most closely related to the number and type of driveway, the median width, and the traffic volume on the highway. His research revealed the number of commercial driveways per mile to be the most significant predictor of the driveway accident rate (15).

In emphasizing the significance of the commercial driveway, Box found that the overall accident frequency at local intersections was two-thirds that of commercial driveways intersecting the major street (12). This fact serves to reinforce the claim that "each driveway creates an intersection with the major street, and is subject to all the accidents common to intersections" (28).

Box found that only 3% of all driveway accidents on major streets in urban areas outside the central business district involved pedestrians (13). Research has attempted to disclose whether vehicles entering or exiting a driveway are involved in the majority of driveway accidents, but the results have thus far been

inconclusive. The Texas Transportation Institute reinforced Box's findings when they discovered driveway accident rates at driveways with uncontrolled width to be 4 times greater than those at driveways with a controlled width (68). Another aspect of Box's study revealed that the accident frequency at service stations increases in direct proportion to the number of driveways connecting to the arterial highway, while no driveway accidents whatsoever were recorded when the service station driveway led to a minor street (12).

Traffic Accident Studies

The preceding discussion offered insights into some typical characteristics of driveway accidents, but only one, that authored by Bruggeman, represented an attempt to statistically relate the driveway accident rate to roadway characteristics. As a result, several traffic accident studies, both urban and rural, were examined in the hope that some of the factors affecting the traffic accident rate will have a similar effect upon the driveway accident rate. Recognition of those factors having the greatest effect upon traffic accidents would be of great assistance during the data collection and analysis phases of this study.

Mulinazzi utilized multiple correlation techniques to relate accident rates to design characteristics and operational controls on urban arterial highways (50). His

findings indicate that the number of accidents per mile increases when the arterial highway ADT is increased, when the number of high volume intersections per mile is increased, when the number of heavily used driveways per mile is increased, when the number of traffic signals per mile is increased, when parking is permitted, and when the operating speed along the arterial highway is decreased. The research further substantiated the importance of access control as an effective accident reduction tool, and it pointed out that most urban accidents occur at intersections or high volume driveways.

Schoppert's study of accident rates on rural two-lane Oregon highways revealed the most important factors in the prediction of traffic accidents to be, in decreasing order of importance, the highway traffic volume, the total number of access points, and design features such as lane width, shoulder width, and sight restrictions (62). As highway traffic volume increases, the accident rate also increases, and as the number of access points, particularly the number of commercial driveways, per mile, increases, the accident rate also increases. Furthermore, the number of commercial driveways per mile was found to be more strongly related to the accident rate than was the number of residential driveways.

Staffeld's study of accident rates on U.S. highway 52 through Minnesota revealed the accident rate to increase as

the traffic volume increased, and as the number of commercial driveways per mile increased (64). Furthermore, the accident rate for sections of the highway containing commercial driveways was found to be 2.9 times greater than those sections with no commercial driveways or with non commercial driveways.

In 1957, Woo used techniques similar to those employed by Mulinazzi to relate the accident rate to roadway characteristics (71). His results indicated that the traffic volume, the congestion index, the lane width, and the total number of entrances per mile were the factors most significantly related to the number of traffic accidents per mile.

Peterson and Michael studied, in part, non intersectional traffic accidents on a high volume urban arterial highway in Lafayette, Indiana, and discovered non intersectional accidents per 100 million vehicle miles to increase when the total number of establishments per mile increased, when the total number of driveways per mile increased, when the arterial highway ADT increased, and when the total number of low volume intersections per mile increased (55).

Head examined 186.4 miles of urban arterial highway in Oregon, and found motor vehicle accident rates to increase when the number of commercial units adjacent to the roadway section increases, when the number of traffic

signals increases, when the number of intersections increases, when the indicated speed decreases, when the arterial highway ADT increases, and when the pavement width increases (30). In addition, it was discovered that the number of residential driveways per mile is one of the least significant of all the roadway characteristics as a predictor of accident rates, and that accident prediction is more reliable when made on the basis of roadway characteristics on 4 lane highways than on the basis of those on 2 lane highways.

Other studies, such as that authored by Cribbins, Horn, Beeson, and Taylor (18), have used similar statistical techniques to arrive at comparable results. While it can be seen that a large family of results is obtained from many different types of data, there seem to be three or four factors, the arterial highway ADT, the number of driveways (particularly commercial driveways) per mile, the number of intersections per mile, and the number of traffic signals per mile, which consistently appear to have the greatest effect upon the traffic accident rate. More important is the fact that these results are seemingly constant in both urban and rural studies, and they are unaffected by the year during which the study was made, and the agency from and by whom the data were collected. This leads one to believe that these factors could also significantly affect the driveway accident rate.

The Effect of Medians on Driveway Accidents

Box disclosed that 60% of driveway accidents involved a left turn maneuver (13). In the same study it was revealed that left turn accidents accounted for 75% of all injury producing driveway accidents. In light of these findings, it seems that the driveway accident rate would be significantly reduced if left turn movements to and from driveways could be eliminated or better controlled. Since signs prohibiting left turning maneuvers at driveways would almost surely be ignored or not seen in time by the motorist, some physical medium would be required.

Research has proven barrier medians to be of great value in the reduction of driveway accidents. Box initiated a before and after experiment to verify this theory (13). He examined an arterial highway which had been widened, provided with a barrier median, and reconstructed with fully channelized driveways. Even though one must attribute the effect of the increased lane width and the transfer of driveway volumes to adjacent signalized intersections to the reduction in accidents, the driveway accident rate was found to decrease by elevenfold as a result of the improvements.

While barrier medians may be utilized to concentrate left turn movements only at pre-selected intersections, pressure may be exerted that would force left turn access at certain driveways along the arterial highway. For such purposes, median openings must be provided. The city of

San Diego, California recommends that such openings not be located closer than 400 feet from the nearest intersection, or 250 feet from the nearest adjacent midblock median opening so as to alleviate congestion and to provide sufficient length for left turn bays (9). North Carolina State University undertook research on the accident experience associated with median openings and found that approximately one-fourth of the total traffic accidents on the arterial highway were occurring at openings in the median between the intersections (16). A sequel to this study proved that median storage in the form of left turn bays significantly reduced accidents at median openings, and the authors implied that the judicious location of median openings is of paramount importance when traffic safety is to be emphasized (18). The Gruen Associates recommend that median opening locations be situated where traffic signals can be installed to control conflicts and to promote progressive traffic movement along the arterial (28). The literature is in agreement on the point that median openings should be kept to a minimum, and, where necessary, they should be located so as to promote safe and efficient travel along the arterial.

Medians do not always have to be restrictive in nature to be effective. A case in point is the two-way left turn lane, which provides refuge for vehicles approaching from any direction to safely carry out ingress and egress

movements to or from driveways with a minimum of interference to through vehicles. Research reveals the accident experience involving two-way left turn lanes to be low, and all reports confirm their excellent safety record throughout the country (42,58,59). This type of design is particularly effective on sections of heavy volume arterial highways with numerous commercial driveways where left turning vehicles pose a constant safety and congestion problem.

Access Control Considerations

Motorists traveling on arterial highways are constantly subjected to two types of roadway friction. Internal friction results from maneuvers within the traffic stream such as weaving and passing. Marginal friction is caused by the presence of parked vehicles and the action of vehicles entering or leaving the arterial highway by way of an intersection or a driveway. Gwynn found in a study of New Jersey's state highway system that 80% of all accidents were the result of marginal friction, and that accidents could be reduced significantly if access were to be controlled to some extent (29).

While it is recognized that urban arterial highways cannot realistically be subjected to full control of access, access control in the form of limiting the number of driveways or combining a system of driveways into one access point can have a substantial effect on decreasing the

accidents resulting from marginal friction. The Texas Transportation Institute found that the road user benefits when the number of driveways along arterial highways is decreased (68).

Access control on existing streets should be undertaken as early as possible in the development stage of adjacent property (10).

Controlling the Number of Driveways

Historically, the legal maximum number of driveways permitted any establishment has been dependent upon the length of frontage that the property occupies along the arterial highway. In 1959 the Institute of Traffic Engineers recommended that frontages less than 100 feet in length contain no more than two driveways, with not more than one driveway for each additional 100 feet of frontage. The policy was amended by warranting three driveways for 175 feet of frontage under special circumstances (38). In 1960 the American Association of State Highway Officials adopted the policy that one driveway be permitted for 50 feet or less of frontage, and not more than two driveways for any additional frontage, except in cases where the frontage exceeds 600 to 1000 feet in length (1). Also in 1960 the Texas Highway Department published their adopted policy. Frontages up to 95 feet in length are permitted only one driveway; frontages ranging from 96 feet to 320 feet are permitted a maximum of two driveways; frontages

ranging from 321 feet to 600 feet are permitted a maximum of three driveways; and special designs must be considered for frontages in excess of 600 feet (27). These represent just three examples of similar policies throughout the United States.

Billion and Scheinbart discovered that the two main driveways associated with multiple driveway service stations in New York handled 80% or more of all ingress and egress movements (6). This finding, when considered together with Box's disclosure that driveway accidents at service stations increase in direct proportion to the number of driveways, would seem to indicate that any more than two driveway connections from service stations to arterial highways would be detrimental to highway safety and unnecessary in terms of vehicular use.

The literature is in agreement when stating that the driveway connections to arterial highways should be kept to a minimum, and, if possible, constructed to minor streets where research has proven the driveway accident rate to be significantly lower. When access to minor streets is not feasible, one may consider routing all driveways into a service road paralleling the arterial (28,44). The rear collector road is another consideration which permits access to arterial fronting property from the rear of property (28). These represent only three suggested ways to deal with the problem of too many driveways connecting to the

arterial highway. While costs and public opinion may serve to decrease the effectiveness of such controls from the engineer's point of view, every consideration should be given toward utilizing some means for decreasing the number of driveways connecting to the arterial highway.

Spacing between Adjacent Driveways

When access manuals were first being developed, the distance between adjacent driveways was specified as a minimum distance. In general, a minimum distance of between 20 and 30 feet was specified, mainly to provide sufficient space between the driveways for parallel parking (27,38,47). In cases where a frontage requires two driveways, minimum spacing between the driveways has been established. The American Association of State Highway Officials specifies a minimum distance between double driveways for single frontages of 10 to 15 feet in urban areas. They also suggest that double driveways be operated as a one-way pair (1). Matson, Smith, and Hurd suggest that double driveways, especially those serving one-way traffic, should be separated as far apart as possible so as to prevent vehicles from building up on the driveways and on arterial highway approaches to the entrance thereby increasing the possibility of congestion on the arterial (45).

With increasing traffic volumes, it became apparent that additional driveways at close spacing provide no additional benefit and may increase the traffic hazard (68).

In 1969, Stover evaluated the spacing of access points and concluded that, in general, no private access point should be permitted unless it is a very high traffic generator, and the location of the access point conforms to the spacing of intermediate intersections (67). Later in the same year the Texas Transportation Institute made some recommendations pertaining to the spacing between adjacent driveways (68). Their research found that parallel parking within 50 feet of a driveway serves to seriously restrict the sight vision of exiting driveway vehicles, and such should not be tolerated. Recognizing that the great speed differential between the arterial highway traffic and the driveway traffic presents many possible accident situations, they concluded that, for high volume generators, driveways spaced at a distance greater than 1.5 times the acceleration distance of the normal vehicle will improve the traffic absorption characteristics of the stream. Adequate spacing between driveways should be provided so as to avoid interference between traffic from two adjacent driveways. A good example is the case where vehicles are backed up waiting to turn left into a driveway, blocking the opportunity for another vehicle to exit an adjacent driveway by way of a left turn. Care must be taken, however, to avoid concentrating efforts to increase spacing on only one side of the street, as driveway jogs can induce the same problem. To help alleviate this, the State of

Wisconsin has adopted a policy for their state highway system in which access points along opposite sides of the highway must be either located directly opposite each other or separated from each other by at least 300 feet (28).

In 1971 the Gruen Associates published their study based upon optimization of arterial highway traffic flow as the primary objective. If there are at least 600 feet between driveways, vehicles can be absorbed under random flow conditions with a minimum of interference (28). The same study supported the American Association of State Highway Officials in considering frontage, or service, roads advantageous in cases where driveways were spaced too close together (1,28). Research shows highways through residential areas with numerous direct driveways to have 6 times the average accident rate of highways equipped with service roads preventing direct driveway access (28).

Spacing between adjacent driveways can be effectively increased by concentrating traffic conflicts at a single point controlled by a traffic signal (28). In this way, by locating driveways where traffic signals can be used to effect progressive traffic movement, spacing becomes practically automatic. In most cases, such design would require the utilization of service roads.

Spacing between Driveways and Adjacent Intersection Legs

As was the case in the study of driveway spacing trends, the distances between driveways and adjacent intersection legs were expressed as a minimum distance when the access manuals were first being developed. The minimum distances varied from 5 feet to 25 feet or more, and they seemed to be based upon providing at least enough room along the side of the road to erect traffic control devices (1,38,47).

Revisions in policy resulted when it was established that driveway to intersection spacing presented a significant hazard to the operation and safety of the arterial highway. For example, Box's study revealed that the proximity of an intersection was found to be significant in 7% of all major route driveway accidents in Skokie, Illinois (13).

Driveways should be located at a distance from an intersection in keeping with the speed of traffic, the type of intersection control, and the sight distance requirements at the intersection (39). Research conducted by the Texas Transportation Institute revealed that insufficient spacing between a driveway and an intersection inadvertently results in another leg being added to the intersection. Furthermore, this insufficient spacing can be the cause of intersection congestion when vehicles must wait in the intersection behind a vehicle making a left turn into a driveway (68). In addition, they suggest that the minimum

distance from the intersection to the driveway should be sufficient for vehicles exiting near corner driveways or entering far corner driveways to weave to the lane from which the next turn is going to be made. The American Association of State Highway Officials recommend that the near side driveway to intersection spacing be two or more times that of the far side spacing at signalized intersections to protect against left turning driveway vehicles causing a queue which would extend into the intersection (1).

"As a general rule, the farther from an intersection a driveway can be located, the less it will affect arterial traffic (28).

PURPOSE

This research was developed to effect an improvement in overall motor vehicle safety, and to expand upon the limited existing driveway accident facts available to engineers and other responsible public officials. The literature search disclosed numerous voids and conflicts of opinion on the subject of driveways and driveway accidents. These facts were translated into the following problem statement.

The purpose of this research is to seek attainment of the following four goals:

1. Develop and evaluate characteristics of driveway accidents;
2. Relate driveway accident rates to the average spacing over a section of roadway between adjacent driveways;
3. Relate driveway accident rates to the average spacing over a section of roadway between a driveway and an adjacent intersection leg;
4. Relate driveway accident rates to roadway characteristics.

Since driveway accidents have been found to represent a significant percentage of total arterial highway traffic

accidents; their reduction would be of great benefit. The reduction of driveway accidents can only be effected when better knowledge of those factors contributing significantly to their occurrence can be recognized.

DATA COLLECTION

Selection of Roadway Study Sections

The method of investigation employed for this study was similar to that used by Mulinazzi (50) in his investigation of traffic accidents on urban arterial highways. Basically, the procedure involves collecting accident data from a large number of arterial highways in pre-selected urban areas and analyzing the data so as to best satisfy the goals of the research. It was believed that informative patterns would result when the analysis was based upon a large number of roadway sections. As a result, this analysis was based upon data accumulated from one hundred roadway sections.

Because the characteristics of arterial streets in small urban areas are considerably different than those of similar streets in larger cities, it was decided to collect data from urban areas whose population, as governed by the 1970 census, exceeded 30,000 (63). It was further decided to impose no upper limit on population so as to obtain in the sample higher volume arterial streets. There are twenty cities in Indiana meeting these qualifications.

Because many trips to each city would be needed to accurately obtain the roadway, traffic volume, and accident data, it was decided, in the interest of conserving time

and resources, to consider only those cities located in central Indiana. Since it was assumed that no more than ten representative arterial highway sections could be obtained from the smallest urban area, the study was limited to ten cities, so as to accommodate the selection of all 100 roadway sections. The ten cities from which the data were obtained, and their corresponding 1970 population are given in Table 1.

Letters were sent to the Chamber of Commerce of each city informing them of the project to be undertaken and requesting from each a detailed street map of the city. After receiving the maps, the task of labeling the perimeter of the central business district, all city boundaries, and all urban arterial streets was undertaken. The completion of these preliminary activities led to the actual data collection.

Roadway Data

In all cases, roadway data were collected by driving to each city and examining each of the premarked arterial highway sections. Because it was obvious from the literature search that many factors could conceivably influence the driveway accident rate, homogeneity with respect to certain variables throughout the length of each section was mandatory. Therefore, before any arterial section was selected for study, the following criteria were evaluated as met:

Table 1. Selected Study Cities and Their Population.

City	1970 Population
Anderson	70,787
Bloomington	43,188
Columbus	31,403
Indianapolis	744,624
Kokomo	44,042
Lafayette-West Lafayette	64,340
Marion	40,043
Muncie	69,080
Richmond	43,999
Terre Haute	70,286

1. Parking characteristics must remain constant.
2. Curb to curb street width must remain constant.
3. No type of median divider can be present. This restriction was necessitated because it was felt that there would be an insufficient number of available divided sections on which reliable analyses could be made regarding the driveway accident rate.

4. No radical changes in traffic volume may occur between the termini of each section.

5. There must have been no major construction on the section, or on land abutting the section, since January 1, 1967. Major construction of this type often has the effect of severely altering the accident experience of a section of roadway. This research study examined accident data on all chosen sections effective January 1, 1968, and it was felt that one year would be sufficient time to introduce drivers to such construction without incurring bias in the sample.

6. The arterial highway section selected for study must be located outside the limits of central business district, and within the city's external boundaries. Arterial highways located within the central business district have characteristics significantly different than those in other parts of the city, while those outside the periphery of the city, by definition, are no longer classified as urban streets.

A roadway section meeting these qualifications was selected for study, and specific roadway factors such as street name, section termini, parking and curb characteristics, the number of through traffic lanes, and whether the arterial operates as a one-way or two-way street were indicated on a prepared inventory form. A copy of this inventory form may be found in Appendix A.

The length of a section and accurate measurements of the location of all driveways and intersection legs connecting to the arterial street were obtained by pacing both sides of the road with a standard measuring wheel. The names of all intersecting streets and the type, if any, of traffic control device present were recorded, and information about every driveway including the type of land use served (residential, commercial, alley, etc.), the name of the establishment and/or the building number of the establishment served by the driveway, the driveway width, and whether or not the driveway was controlled by some kind of traffic control device was indicated. The location of outstanding landmarks such as railroad crossings was included for control purposes. This data collection procedure proved to be of invaluable assistance for the following reasons:

1. Spacing between driveways and spacings between driveways and intersections could be easily obtained once the measurements were drawn to scale in the form of a map in the office.

2. Because of the complexity of some accident record filing systems, the knowledge of the building number or the name of the establishment could be used to ascertain whether a driveway accident actually occurred within the limits of the study section.

3. The remainder of the roadway data, such as the number of intersections, the number of driveways, and the number of traffic control devices, can be collected without any duplication of procedure.

Additional work involved in pacing the section was minimal, because it would have been necessary to measure the length of the arterial highway section anyway. The measuring wheel accumulates distance as it is pushed along the edge of the road, and the accumulated distance is recorded every time a break in the curb is reached. An example of one side of a typical paced roadway section is given in Figure 1. This section, the south side of section number 21, 2nd Street in Marion, is not drawn to scale, as the cumulative distances shall later be utilized to construct a scale model of the roadway section. The length of each section is computed by considering only the distance from the nearside curb to the nearside curb of the two section terminals, as indicated in Figure 1. This was done to avoid a bevy of intersectional accidents, none of which mean anything to the driveway accident rate, but may be the result of entirely different roadway characteristics on the

LEGEND

COMM. COMMERCIAL DRIVEWAY
 RES RESIDENTIAL DRIVEWAY
 IND INDUSTRIAL DRIVEWAY
 RELIG CHURCH
 SIG TRAFFIC SIGNAL
 4 WAY 4 WAY INTERSECTION
 3 WAY 3 WAY INTERSECTION

— N —

WIDTH AT GENEVA 30'
 WIDTH AT BALDWIN 30'
 HOUSE # AT GENEVA 1718 +
 HOUSE # AT BALDWIN 1411 -

DRIVEWAYS

RES	6
COMM	5
IND	1
RELIG	1
ALLEY	1
TOTAL	14

INTERSECTIONS

3 WAY	0
4 WAY	3
5 WAY OR MORE	0
TOTAL	3

FIGURE 1. FIELD COPY — PACED SECTION No. 21
 (SOUTH SIDE OF ROAD) — MARION

other side of the section terminal. A break in the curb is indicated whenever an intersection or driveway is encountered. A driveway is recognized on Figure 1 as the curb cut formed by the shorter of the two different sizes of horizontal lines, while the intersection legs are detailed with longer horizontal lines.

The roadway data for all 100 sections were collected by adhering to these standards. Table 2 is a listing by section number of all 100 sections including the city from which the section originated, the street name, the section terminals, the section length, the 1969 ADT, and a brief description of the predominant abutting land use. The 100 sections averaged 0.604 miles in length.

Traffic Volume Data

The collection of accurate traffic volume data for all sections was an important phase of the overall data collection procedure. The literature search revealed average daily traffic volume (ADT) on the roadway section to possess a strong relationship with accident rates. The computation of one of the two accident rates to be utilized in this study, the number of driveway accidents per 100 million vehicle miles, required the knowledge of the ADT for each roadway section. On the basis of these two facts, it was decided to employ ADT as the variable denoting traffic volume in this study.

Table 2. Study Section Characteristics.

City	Street	Sec. No.	Terminal Points	Length (Mi.)	1969 ADT	Surrounding Area Description
Lafayette	Northwestern	1	Stadium-Lindberg	1.102	13360	Res.
	Teal	2	9th-18th	0.493	14146	Res, Com
	Main	3	South-Earl	1.165	10829	Res, Com
	Union	4	5th-14th	0.503	9708	Res, Com
	Columbia	5	10th-Main	0.308	6287	Res
	Greenbush	6	Elmwood-U.S. 52 Bypass	0.394	8044	Res
	Elmwood	7	18th-Wayne	0.533	12019	Res, Com
	Main	8	Columbia-9th	0.363	7212	Res, Com
	9th	9	Potomac-N&W			
	18th	10	Railroad Tracks Logan-Virginia	1.046 0.443	9384 9985	Res Res
Kokomo	Markland	11	Buckeye-Plate	0.875	15376	Com
	Apperson Way	12	Jefferson-North	0.494	4728	Res
	Morgan	13	Webster-Apperson Way	0.484	6446	Res, Com
	Sycamore	14	Phillips-Webster	0.523	7667	Res
	Phillips	15	Walnut-Elm	0.586	5460	Res, Com
	W. Jefferson	16	Korby-Wabash	0.421	3048	Res, Com, Ind
	Taylor	17	Phillips-Washington	0.630	2019	Res
	Mulberry	18	Washington-Phillips	0.633	1638	Res
	Washington	19	Taylor-Davis	0.708	18312	Com
	Main	20	Park-Markland	0.533	4334	Res
Marion	W. 2nd	21	Geneva-Baldwin	0.403	9054	Res, Com
	Wabash	22	Quarry-Kem	0.522	6344	Res
	Washington	23	Grant-McKinley	0.554	4593	Res, Com
	Washington	24	11th-26th	0.916	6793	Res, Com
	Adams	25	26th-11th	0.933	6644	Res, Com
	E. 38th	26	S. Adams-Lincoln	0.914	5962	Res, Com, Ind

Table 2. Continued.

City	Street	Sec. No.	Terminal Points	Length (Mi.)	1969 ADT	Surrounding Area Description
Marion (continued)	S. Adams	27	38th-32nd	0.611	8248	Res, Com, Ind
	9th	28	New Jersey-Park	0.864	3732	Res, Com, Ind
	5th	29	Western-Boots	0.676	1187	Res
	3rd	30	E.-Gallatin	0.429	11777	Res, Com
Muncie	McGalliard	31	Lanewood-Walnut	0.715	11912	Res, Com
	Tillotson	32	Euclid-Burnell	0.374	11731	Res
	Memorial	33	Utica-Elliott	0.648	13246	Res, Com
	Jackson	34	Madison-Onio	0.487	5865	Res, Com
	Main	35	Wolf-Munroe	0.512	7096	Res, Com
	Broadway	36	Lowell-Centennial	0.483	17826	Res, Com
	Madison	37	24th-13th	0.764	16585	Com
	Macedonia	38	24th-13th	0.747	6929	Res, Com
	Riverside	39	Clarkdale-Forest	0.434	3014	Res
	Madison	40	9th-Kirby	0.484	18839	Com
Anderson	Meridian	41	17th-25th	0.590	6268	Res, Com
	Main	42	24th-19th	0.326	7238	Res
	8th	43	Henry-Brown	0.747	10507	Res, Com
	Madison	44	5th-Vanburskirk	0.635	10799	Res, Com
	Cross	45	Lowell-Silver	0.452	7365	Res
	Nichol	46	Arrow-Madison	0.506	8094	Res
	Broadway	47	Grand-Cross	1.163	14743	Res, Com
	9th	48	John-Jackson	0.349	1770	Res, Com
	8th	49	College-Nursery	0.502	9340	Res
	State Rd. 109	50	Hillcrest-5th	0.474	19248	Res, Com

Table 2. Continued.

City	Street	Sec. No.	Terminal Point	Length (Mi.)	1969 ADT	Surrounding Area Description
Richmond	S. 8th	51	S. A-S. F	0.467	7453	Res, Com
	S. 9th	52	S. L-S. F	0.419	7313	Res, Com
	N. A	53	12th-7th	0.343	8523	Com
	S. E	54	10th-16th	0.434	8097	Res, Com
	S. 23rd	55	S. L-S. E	0.490	1469	Res
	E. Main	56	28th-Elks Country Club	0.658	18048	Res, Com
	W. Main	57	N.W. 18th-N.W. 6th	0.924	6035	Res
Columbus	N.W. 5th	58	S.W. A-N.W. E	0.514	7320	Res, Com
	Peacock	59	Salisbury-N.W. 13th	1.073	1668	Res, Ind
	S. 5th	60	S. E-E. Main	0.503	5973	Res, Com, Ind
	Chestnut	61	16th-24th	0.508	1864	Res
	California	62	24th-16th	0.510	1313	Res
	Washington	63	8th-17th	0.610	12529	Res, Com
	25th	64	Washington-Maple	0.687	11565	Res, Com
	17th	65	Elm-Chestnut	0.426	2181	Res
	U.S. 31 Bypass	66	17th-24th	0.462	13333	Com
	Central	67	11th-17th	0.410	11810	Com, Ind
Bloomington	25th	68	Griffa-Taylor	0.696	14590	Res, Com
	Indiana	69	Mapleton-Brooks	0.547	2111	Res
	8th	70	Sycamore-Central Pl.	0.610	1153	Res
	Walnut	71	Hillside-1st	0.605	17010	Res, Com
	10th	72	Lincoln-Forrest	0.459	13140	Res, Com
	College	73	17th-11th	0.388	13553	Res, Com
	Walnut	74	10th-17th	0.499	15242	Res, Com
	Rogers	75	4th-11th	0.519	5547	Com, Ind
	2nd	76	Walker-Rogers	0.396	12886	Res, Com
	Hillside	77	S. Henderson-High	0.985	1942	Res, Ind

Table 2. Continued.

City	Street	Sec. No.	Terminal Point	Length (Mi.)	1969 ADT	Surrounding Area Description
Bloomington (continued)	1st	78	Fess-Jordan	0.510	4068	Res
	3rd	79	Jordan-S. Fess	0.502	13683	Res
	Woodlawn	80	Hillside-Maxwell	0.497	1717	Res, Ind
Terre Haute	Ohio	81	13th-19th	0.496	6365	Res
	Walnut	82	18th-13th	0.432	4286	Res
	Poplar	83	12th-22nd	0.831	8356	Res, Com
	25th	84	8th-Maple	0.498	7329	Res, Com
	13th	85	6th-Maple	0.623	9592	Res, Com, Ind
	College	86	4th-10th	0.499	4292	Res, Com
	7th	87	Wheeler-Hulman	0.860	9085	Res, Com
	8th	88	Ohio-Deming	0.463	5680	Res, Com
	13th	89	College-Poplar	0.496	6059	Com, Ind
	Fort Harrison	90	14th-23rd	0.645	5138	Res, Com
Indianapolis	N. Meridian	91	46th-54th	0.752	18047	Res
	10th	92	Rural-Kealing	0.671	15345	Com
	Arlington	93	English-E. Washington	0.696	8039	Res
	N. Illinois	94	17th-24th	0.780	18792	Com
	E. New York	95	Forest-Lasalle	0.594	21052	Res, Com
	E. Michigan	96	Lasalle-Forest	0.594	18520	Res, Com
	N. Keystone	97	E. 25th-E. 33rd	0.865	16812	Res, Com
	38th	98	N. Tacoma-Denwood	0.980	31034	Res, Com
	E. 46th	99	Haverford-Hillside	0.684	12417	Res, Com
	College	100	E. 39th-E. 46th	0.874	11005	Res, Com

Traffic volume data for all roadway sections were obtained from three sources. Such data for 52 of the sections were obtained from the Indiana State Highway Commission, Division of Planning, who maintained volume counts on every urban extension of the state highway system. Volume counts for 29 of the sections were obtained from the study cities in the form of traffic counts made by city employees or from traffic engineering and/or planning studies made for the city. Traffic volume data for the remaining 19 study sections had to be obtained through field work. Pneumatic detectors were placed at representative locations on each of the 19 sections for a 48 hour period to determine traffic volume. In all cases, the data obtained for each section were verified as being reasonably accurate before their use in analysis was permitted. New counts were obtained when this criterion could not be satisfied.

The only two types of data collected were the average daily traffic volume (ADT) for a given year, and the average 24 hour weekday count for a given month and year. Since the average 24 hour weekday count could easily be converted into ADT, there was no problem in determining the ADT for each roadway section for a given year.

The average 24 hour weekday volume count was converted into ADT by applying the appropriate volume expansion factor as recommended by the Indiana State Highway Commission. Since all 100 roadway sections are classified as urban arterial highways, the factors for "State Roads in Suburban

Areas" were considered appropriate. All traffic counts obtained from the three sources were ascertained to have been taken only on either a Monday, Tuesday, Wednesday, or Thursday during a given month and year. The average 24 hour weekday count was determined by dividing the total volume by the number of days during which the volume was obtained. This figure was then multiplied by the factor corresponding to the month and year during which the count was taken to determine the ADT for that year. A listing of these factors by month and year is given in Table 3. In cases where the counts were made in 1972, the 1971 factors for the same month were utilized, as the Indiana State Highway Commission did not have the 1972 factors compiled when the analysis of the data was undertaken.

The Indiana State Highway Commission assumes, for purposes of analysis, an ADT growth rate of 4% compounded annually. By using this figure the ADT's for all 100 study sections were converted into 1969 and 1971 ADT's, since these two values will assume the most importance in the analysis of data. A listing of the 1969 ADT for each of the roadway sections can be found in Table 2.

Accident Data

Accident data were collected for each of the 100 roadway sections for the period from January 1, 1968 to December 31, 1971. The data recorded for the first three years, January 1, 1968 to December 31, 1970, were utilized in the

Table 3. Factors to Expand 24 Hour Weekday (Mon., Tues., Wed., Thur.) Volumes to ADT
(State Roads in Suburban Areas).

Month of Year	Year					
	1966	1967	1968	1969	1970	1971
January	1.188	1.135	1.204	1.239	1.208	1.222
February	1.206	1.172	1.148	1.141	1.144	1.210
March	1.125	1.043	1.109	1.071	1.031	1.073
April	1.050	1.010	1.061	1.025	1.067	1.025
May	1.031	1.059	1.017	0.954	0.988	0.987
June	0.982	0.960	0.988	0.949	0.950	1.040
July	0.936	0.959	0.989	0.931	0.942	0.924
August	0.937	0.966	0.983	0.925	0.928	0.931
September	1.002	1.017	1.015	0.967	0.919	0.931
October	1.056	1.059	1.008	0.984	0.943	0.944
November	1.076	1.093	1.008	1.007	0.970	0.967
December	1.041	1.056	1.030	1.028	0.985	0.962

development of spacing criteria and in the analysis of factors affecting the driveway accident rate, while the data for the year 1971 were used to test some of the results obtained. The three year driveway accident history was used to insure an adequate sample size of accident data so as to reduce the possibility of using accident statistics derived from the chance occurrence of many unexplained driveway accidents which can occur along a section of arterial highway during a short period of time. May concluded that a three year accident history is the minimum period of time to be used in making an accident study, and he statistically proved that little more is gained by using a longer study period than 3 years when collecting accident data in a particular location (46).

The majority of the accident data was collected from the Accident Records Divisions of the police departments of the ten study cities. On account of the filing systems employed, the 1968 accident data from both Muncie and Columbus, and the entire four year accident history of section number 26 in Marion were not immediately available, and they had to be obtained from the Accident Records Division of the Indiana State Police in Indianapolis. In all cases, however, the accident information was derived only from the standard Indiana State Police accident report form as filed by the investigating police officer, so as to maintain some homogeneity in the data sources. A copy of this accident reporting form is found in Figures 2 and 3.

Information pertaining to the total number of traffic accidents and the number of driveway accidents was obtained for each roadway section. The total number of traffic accidents was recorded for purposes of computing driveway accidents as a percentage of total accidents. Whenever a driveway accident was discovered, pre-selected information from the accident report was transferred to a questionnaire. A separate questionnaire, containing information such as the driveway accident location, the accident severity, the time of the accident occurrence, the circumstances and prevailing conditions surrounding the accident, and the actions of the driveway vehicle, was prepared for each driveway accident occurring on the 100 roadway sections over the four year study period. A copy of this questionnaire is included in Appendix B.

ANALYSIS OF DATA

Driveway Accident Rates

"Accident records are often used to compare the traffic hazard in different areas for the same period of time, or in the same areas or at the same locations for different periods of time. To effectively compare hazard, accident comparisons must be based upon exposure" (70). The accident rate is that measure of exposure by which the accident experience can be compared. Two forms of accident rates were selected for use in this study. The first, the number of driveway accidents per mile per year, was selected because it expresses the accident rate in a form which can be easily understood by the engineer and the layman. This rate is simply the quotient of the annual number of driveway accidents based on a three year average and the length of the roadway section, in miles, from which the accidents were obtained. It can be expressed mathematically as follows:

$$\text{Rate} = \frac{A}{S}$$

Where

Rate = Driveway accidents per mile per year.

A = The annual number of driveway accidents based on a 3 year average.

S = Section length, in miles

The second, driveway accidents per 100 million vehicle miles, was selected because the Traffic Engineering Handbook suggests that the accident involvement rate be expressed in this manner. This rate can be expressed mathematically as follows:

$$\text{Rate} = \frac{(A)(100,000,000)}{(S)(Y)(365)}$$

Where

Rate = Driveway accidents per 100 million vehicle miles.

A = The annual number of driveway accidents based on a 3 year average.

S = Section length, in miles.

Y = Annual Average Daily Traffic Volume (AADT).

In this analysis, because a 365 day count could not realistically be taken on all 100 sections, ADT was assumed to approximate the AADT.

A total of four accident rates were computed for each roadway section, two involving accidents per mile per year and two involving accidents per 100 million vehicle miles. Each of these was further subdivided by computing each accident rate based on a three year accident history, using the 1968 to 1970 data, and upon a one year accident history, using the 1971 data. The four driveway accident rates for each section are listed in Table 4.

While it has been statistically proven that the best results in an accident study are obtained when the annual

Table 4. Driveway Accident Rates.

Section Number	Accidents/Mile/Year		Accidents/100 Million Vehicle Miles	
	1968-1970 Data	1971 Data	1968-1970 Data	1971 Data
1	9.679	6.352	198.500	120.436
2	16.227	26.369	314.280	472.185
3	5.722	5.150	144.778	120.466
4	3.976	5.964	112.212	155.622
5	1.082	3.247	47.291	130.812
6	3.384	5.076	115.260	159.853
7	17.511	18.762	399.161	395.400
8	0.918	0.000	34.884	0.000
9	3.824	1.912	111.647	51.611
10	3.010	0.000	82.584	0.000
11	15.238	30.857	271.515	508.359
12	0.675	0.000	39.100	0.000
13	3.444	2.066	146.359	81.190
14	3.187	1.912	113.875	63.175
15	2.844	0.000	142.714	0.000
16	2.375	2.375	213.506	197.381
17	0.528	1.585	71.684	198.804
18	0.000	1.580	0.000	244.253
19	23.070	12.712	345.154	175.832
20	3.127	0.000	197.670	0.000
21	3.308	0.000	100.115	0.000
22	0.639	0.000	27.577	0.000
23	2.407	3.610	143.562	199.088
24	0.000	1.092	0.000	40.710
25	0.000	2.144	0.000	81.728
26	1.459	4.376	67.036	185.950
27	6.547	18.003	217.459	552.898
28	0.772	0.000	56.645	0.000
29	0.000	0.000	0.000	0.000
30	7.770	4.662	180.757	100.272

Table 4. Continued.

Section Number	Accidents/Mile/Year		Accidents/100 Million Vehicle Miles	
	1968-1970 Data	1971 Data	1968-1970 Data	1971 Data
31	2.331	5.594	53.612	118.963
32	0.000	0.000	0.000	0.000
33	1.029	1.543	21.279	29.511
34	2.053	0.000	95.920	0.000
35	0.651	0.000	25.136	0.000
36	4.831	2.070	74.248	29.419
37	18.325	17.426	302.710	259.871
38	1.785	0.000	70.576	0.000
39	0.768	0.000	69.816	0.000
40	15.840	10.331	230.362	138.903
41	2.260	3.390	98.779	136.980
42	1.023	0.000	38.703	0.000
43	8.032	4.016	209.440	96.814
44	1.575	0.000	39.953	0.000
45	0.000	0.000	0.000	0.000
46	2.635	9.881	89.193	309.257
47	25.222	15.477	468.709	265.007
48	1.910	0.000	295.677	0.000
49	3.320	0.000	97.388	0.000
50	21.097	6.329	300.292	83.289
51	1.428	2.141	52.477	72.778
52	0.796	0.000	29.804	0.000
53	5.831	11.662	187.435	346.606
54	5.376	2.304	181.916	72.088
55	0.680	0.000	126.873	0.000
56	28.369	31.915	430.645	447.918
57	1.443	0.000	65.508	0.000
58	5.188	11.673	194.179	403.957
59	1.864	0.932	306.155	141.537
60	1.988	5.964	91.190	252.907

Table 4. Continued.

Section Number	Accidents/Mile/Year		Accidents/100 Million Vehicle Miles	
	1968-1970 Data	1971 Data	1968-1970 Data	1971 Data
61	0.000	0.000	0.000	0.000
62	1.307	3.922	272.760	756.089
63	10.929	13.115	238.984	265.153
64	5.822	4.367	137.932	95.642
65	0.000	0.000	0.000	0.000
66	12.987	10.823	266.853	205.608
67	3.252	2.439	75.442	52.311
68	5.747	1.437	107.920	24.945
69	0.609	1.828	79.088	219.389
70	1.639	0.000	389.536	0.000
71	8.815	8.264	141.986	123.070
72	2.179	4.357	45.426	83.998
73	6.014	7.732	121.567	144.508
74	15.364	8.016	276.167	133.223
75	3.854	3.854	190.332	175.962
76	17.677	12.626	375.830	248.189
77	0.338	2.031	47.742	264.900
78	0.654	0.000	44.019	0.000
79	5.976	5.976	119.658	110.627
80	0.671	0.000	107.019	0.000
81	0.000	0.000	0.000	0.000
82	0.000	0.000	0.000	0.000
83	3.209	1.203	105.215	36.478
84	8.032	4.016	300.257	138.803
85	3.210	4.815	90.388	127.161
86	2.004	2.004	127.923	118.252
87	1.938	1.163	58.443	32.421
88	4.320	2.160	208.357	96.326
89	0.672	0.000	30.388	0.000
90	4.134	1.550	220.456	76.438

Table 4. Continued.

Section Number	Accidents/Mile/Year		Accidents/100 Million Vehicle Miles	
	1968-1970 Data	1971 Data	1968-1970 Data	1971 Data
91	1.330	3.989	20.188	55.993
92	4.968	14.903	88.695	245.996
93	2.395	1.437	81.610	45.272
94	3.846	3.846	58.318	53.919
95	2.806	1.684	36.515	20.256
96	2.806	0.000	41.508	0.000
97	1.927	3.468	31.399	52.254
98	10.544	15.306	93.086	124.928
99	2.924	0.000	64.516	0.000
100	4.195	1.144	104.442	26.335

average of a 3 year accident history is used to develop accident rates, one must be alert to the possibility that the three years selected may be in disagreement with each other. Under such circumstances, it is difficult to determine which, if any, of the three years is representative of the accident conditions for the given set of roadway factors compiled. If it is assumed that the driveway accident rate is accurate only when this rate is derived from a three year accident history in which it can be stated that the three numbers of accidents came from the same population, then one may utilize a statistic by which the reliability of each accident rate can be evaluated. This can be done by means of the chi-square test of goodness of fit (54), which utilizes the test statistic

$$\chi^2 = \sum_{i=1}^N \frac{d_i^2}{\bar{x}}$$

Where

N = The number of years of accident records utilized
($N = 3$ in this study).

d_i = The difference between the number of driveway accidents occurring in the year i and the average number of driveway accidents per year over the three study years.

$\bar{x}$ = The average number of driveway accidents per year over the three study years.

This statistic was computed for each of the 100 roadway sections, and compared to a tabled chi-square statistic at a given significance level with $(N-1)$ degrees of freedom.

As an example, consider the three year driveway accident history of section number 11, a 0.875 mile long stretch of Markland Street in Kokomo. There were 8 driveway accidents on this section in 1968, 18 in 1969, and 14 in 1970. The chi-square test was used to test the null hypothesis that the three given numbers of driveway accidents came from the same population, against the alternate hypothesis that they did not. The value of $\bar{x}$ is computed by summing the three year accident history and dividing by 3, giving $\bar{x} = \sum x_i / 3 = 40 / 3 = 13.33$ driveway accidents per year. The corresponding values of d_i are computed as $d_1 = 8 - 13.33$; $d_2 = 18 - 13.33$; $d_3 = 14 - 13.33$. The chi-square statistic with $N-2$ degrees of freedom is:

$$\chi^2 = \sum_{i=1}^{N=3} \frac{d_i^2}{\bar{x}} = \frac{(-5.33)^2}{13.33} + \frac{(4.67)^2}{13.33} + \frac{(.67)^2}{13.33} = 3.80$$

Using a significance level of $\alpha = 0.10$, the chi-square test statistic, given as $\chi^2(1 - \alpha, 2)$, is 4.61. Since the computed value of $\chi^2 = 3.80$ was less than the table value of $\chi^2 = 4.61$, the goodness of fit test did not indicate any significant difference in the number of driveway accidents occurring annually over the three year period. As a result, it was assumed that the accidents for each year were obtained from the same population, and that their average would

be a good basis upon which to calculate the driveway accident rates for Markland Street.

The chi-square goodness of fit test was applied to the remaining 99 roadway sections in a similar manner, and only eight of the sections were found to produce a chi-square statistic which exceeded the table value of 4.61. In other words, 8% of the roadway sections were found to possess a significant variance in their number of driveway accidents. A listing of these eight sections is found in Table 5. No apparent operational reasons could be uncovered for this occurrence because of the strict constraints placed upon the selection of study sections in the early data collection phase. However, since the testing procedure was based upon a significance level of 0.10, it is entirely possible that a "Type 1" error could account for the variability displayed in the eight sections. A "Type 1" error results when a hypothesis is actually true, but it is rejected when the null hypothesis is tested. Driveway accident rates utilizing the average of the three annual totals are especially important in that phase of the analysis in which driveway accident rates are related to roadway characteristics, so it was decided to compare the results of a stepwise regression analysis performed utilizing all 100 roadway sections against the results of a stepwise regression analysis using only those 92 roadway sections found to "pass" the chi-square goodness of fit test. In all cases, the multiple correlation coefficient (R^2) was greater by a value of

Table 5. Roadway Sections Displaying Significant Variance
in 3 Year Accident History.

Section Number	Number of Driveway Accidents			Chi Square Value
	1968	1969	1970	
1	18	6	8	7.75
9	2	8	2	6.00
16	0	0	3	6.00
40	15	3	5	10.78
57	4	0	0	8.00
64	8	1	3	6.50
73	2	5	0	5.43
92	7	2	1	6.20

approximately 0.04 when the analysis was made without the data from the eight sections listed in Table 5. As a result, every analysis utilizing the driveway accident rate based upon the average of the 3 year accident history was performed utilizing only those 92 roadway sections which passed the chi-square goodness of fit test.

Driveway Accident Characteristics

The knowledge of specific driveway accident characteristics has been of great benefit to agencies responsible for designing better and safer highway transportation facilities. Box's research not only alerted these agencies to the magnitude of the driveway accident problem, but it indicated many characteristics, such as higher arterial highway ADT and more commercial driveways per mile, whose presence frequently was associated with the occurrence of a driveway accident. It will be the purpose of this phase of the analysis to highlight the more significant driveway accident characteristics.

The majority of the data for this phase of the analysis was obtained from the investigating police officer's accident report form. A copy of this accident report form and the questionnaire used to extract pertinent data from each driveway accident can be found in Figures 2 and 3, and in Appendix B respectively. This phase of the analysis will disclose and evaluate driveway accident characteristics based upon the entire four year accident history for all

100 study sections. While many of the following characteristics could be categorized as miscellaneous information, it is conceivable that such knowledge could materially affect driveway regulations.

Characteristics Based Upon All 100 Roadway Sections

The four year accident history of 100 central Indiana arterial highway sections, totaling 60.436 miles in length, revealed a total of 1212 driveway accidents. This represented 13.95% of all reported traffic accidents for these same sections. However, if the cases do not include those situations where the driveway vehicle (i.e., the vehicle performing the ingress or egress movement to or from the driveway) was not directly involved, but whose actions directly resulted in an accident, driveway accidents represented 12.60% of the total number. Both figures can be considered comparable to Box's finding that 12% of all major street accidents were driveway accidents. The magnitude of the driveway accident problem is reinforced by these figures.

The distribution of driveway accidents by day of week, as depicted in Figure 4, is indicative of both arterial highway traffic volume and driveway use. The fewest number of driveway accidents occurred on Sunday, when traffic volumes are lowest and when many business establishments are closed, while a significantly higher number was experienced on

FIGURE 4. DRIVEWAY ACCIDENT DISTRIBUTION BY DAY OF WEEK

Friday and Saturday, when traffic volumes are heavier and more vehicles, demanding access, undertake, on the average, more shopping trips. The fact that 71.62% of all driveway accidents involved a movement into or from a commercial driveway further serves to emphasize this effect by the day of week. An attempt was made to evaluate differences in the number of driveway accidents occurring in different months, but no significant difference between the twelve months could be established.

In terms of accident severity, 85.56% of the driveway accidents recorded resulted in property damage only. The remaining 14.44% involved personal injury, with none of the driveway accidents resulting in a fatality. This in no way implies that a fatality resulting from a driveway accident could not occur, but it seems safe to consider the driveway accident as typically a property damage producing accident.

Left turn movements, to or from a driveway, resulted in 64.60% of all driveway accidents. Of perhaps even greater significance is the fact that 76.00% of all driveway accidents resulting in personal injury involved a left turn maneuver. Both of these figures are substantially in agreement with those of Box, whose study revealed left turn maneuvers to account for 60% of all driveway accidents, and 75% of all driveway accidents resulting in personal injury involved a left turn maneuver (13). It would appear that

regulations restricting all left turn driveway movements would have a tremendous impact upon the driveway accident rate.

A fairly even distribution between driveway vehicle ingress and egress movements was noted, as 53.47% of the driveway accidents involved a vehicle entering a driveway, while 46.53% involved a vehicle exiting a driveway.

Obscured vision, in the form of parked vehicles, landscaping, structures, fogged windows, ice and snow, and heavy rainfall, was found to be a cause of driveway accidents in only 13.53% of the reported cases. Less significant, but of importance, is the fact that only 1.57% of all driveway accidents could be traced to a malfunction of the driveway vehicle.

60.07% of the driveway accidents were of the right angle variety, while 33.08% involved a rear end collision. Driveway vehicles backing into parked cars, head on collisions, and sideswipes accounted for the remaining small percentage. A majority of the rear end collisions were the result of the driveway vehicle being struck while waiting for traffic to disperse sufficiently to allow a left turn into a driveway.

Driveway vehicles were struck by through traffic vehicles in 57.01% of the cases, whereas they struck the through traffic vehicle in 33.34% of the cases. The driveway vehicle was not directly involved in the accident in 9.35% of the cases.

Of all driveway accidents, 72.28% occurred during daylight hours, while the remainder occurred under darkness, dawn, or dusk conditions. This factor serves to re-emphasize the important contribution of ADT and driveway usage to the driveway accident rate, as both conditions are of greater magnitude during the daylight hours. A total of 75.00% of the driveway accidents occurred during periods of non-precipitation and 70.05% of the driveway accidents occurred under dry pavement conditions. Such results might occur from the fact that drivers tend to be more alert and compensating while driving under adverse weather and pavement conditions, but are probably more likely to be due to the lower number of inclement weather days in a year. Even without the aid of meteorological data, it is safe to assume that the percentage of inclement days is significantly less than that of fair days, and that the pavement is dry a larger percentage of the time than it is wet.

Characteristics Based Upon Significant Data Splits

While the analysis of the characteristics of the four year accident history of all 100 sections taken together provided many insights into driveway accident characteristics, substantially more was obtained when the roadway sections were split into two or more logical categories, with observations as to corresponding differences between the groups being made. The procedure involves examining all characteristics of the 100 roadway sections and dividing

them into groups satisfying at least one of the two following criteria:

1. A split may be made between groups displaying obviously dissimilar characteristics, such as one-way streets vs. two-way streets.

2. A split may be made on the basis of statistical analysis which proves very dissimilar characteristics with respect to certain levels or categories of the data.

Three data splits were recognized and analyzed in this phase of the study.

The sample consisted of 29 one-way streets and 71 two-way streets. While regression analysis and data interaction techniques did not show this logical split to be as significant as the two to follow, the results obtained were indeed rewarding. Over a four year period, two-way streets experienced almost 2.75 times the number of driveway accidents per mile as one-way streets (23.843 to 8.761). Driveway accidents on one-way streets represented only 6.37% of the total one-way street accidents, while on two-way streets they represented 16.35% of the total. The average ADT for the 29 one-way street sections was found to be 7582 vehicles per day, while the average volume was 9905 vehicles per day on the 71 two-way street sections. Two-way streets also had, on the average, more commercial driveways per mile than did one-way streets. The one-way street sections averaged 16.20 commercial driveways per mile while the two-way

street sections averaged 21.32 commercial driveways per mile. One must use caution in interpreting the results of this particular analysis. On the surface, it would seem that a substantial reduction in the driveway accident rate could be realized by reverting from two-way to one-way operation on a particularly hazardous section of arterial highway. While this would seem to be the case, it must be remembered that one-way streets seem to be associated with a lower ADT and fewer commercial driveways per mile. In addition, it is recalled that 64.60% of all driveway accidents involved a left turn maneuver. The difference between the accident experience on one-way and two-way facilities can be explained in light of the differences in left turn movements between two-way and one-way streets. Left turn from or to one-way streets only encounter conflicts from one direction of flow, while such maneuvers to or from two-way streets encounter conflicts from two directions of flow. Additional study is certainly required to verify or refute this theory, but it must remain as a distinct possibility.

The second data split was made on the basis of the number of traffic lanes on the arterial highway available for through traffic flow. Analysis based upon such a split was performed when regression analysis revealed this variable to be significant at a number of different levels. The entire sample ranged from one lane to four lanes. The results of the analysis can be found in Table 6. There can

Table 6. Driveway Accidents Per Mile, Commercial Driveways Per Mile, and ADT as a Function of the Number of Through Lanes in Both Directions (4 Year Period).

Number of Lanes	Number of Section Samples	Driveway Accidents Per Mile	Commercial Driveways Per Mile	ADT
1	3	1.378	7.581	1,713
2	74	12.011	15.777	7,843
3	5	15.272	28.115	11,648
4	18	51.194	34.395	15,522

be little doubt that an increase in the number of through traffic lanes was, on the average, accompanied by increases in the number of driveway accidents per mile, the number of commercial driveways per mile, and the ADT. One must not overlook the possibility of interactions between ADT, the number of lanes, and the number of commercial driveways per

mile, as any possible combinations of these variables could have a significant effect upon the driveway accident rate. Such interactions were found to take on greater importance when roadway factors were analyzed in relation to the driveway accident rates.

The final data split was made on the basis of certain pre-selected ranges of ADT. The ADT ranges into which the sections were categorized were determined on the basis of a plot of driveway accidents per mile vs. ADT, and selecting as intervals those groupings which seemed to possess similar characteristics. While a consistent relationship did not occur, there was a definite trend toward more driveway accidents per mile and more commercial driveways per mile in the higher ADT ranges, as indicated in Table 7. In all ranges of ADT except 8801 to 10,200 vehicles per mile, both driveway accidents per mile and commercial driveways per mile increased with ADT. One reason for this abrupt reversal could have been the small sample size of 7 on which the two rates were based. A closer look at the data, however, revealed additional information. The ADT range from 0 to 5000 vehicles per day included 19 sections with 2 through lanes, and 3 sections with 1 through lane; the ADT range from 5001 to 6800 vehicles per day included 15 sections with 2 through lanes, and 1 section with 3 through lanes; the ADT range from 6801 to 8800 vehicles per day included 15 sections with 2 through lanes, 1 section with 3 through

Table 7. Driveway Accidents Per Mile and Commercial Driveways Per Mile as a Function of ADT (4 Year Period).

ADT Range	Number of Section Samples	Driveway Accidents Per Mile	Commercial Driveways Per Mile
0-5000	22	3.944	4.970
5001-6800	16	7.051	15.226
6801-8800	17	13.432	16.906
8801-10200	7	11.644	13.470
10201-11900	8	17.666	17.854
11901-14600	13	32.388	24.714
Over 14601	17	48.837	42.592

lanes, and 1 section with 4 through lanes; and the ADT range from 8001 to 10,200 vehicles per day included all 7 sections with 2 through lanes. Slight as it may seem, the first three levels of ADT were accumulating more roadway sections with a greater number of lanes while associating an increase in ADT with an increase in the number of driveway accidents per mile and in the number of commercial driveways per mile. However, when the ADT range increased to the fourth level, a decrease in the number of sections with more than 2 lanes was experienced along with a decrease in the two rates. It is conceivable that some type of interaction between the number of lanes and any one or more of the other variables could have produced this phenomenon.

Driveway Spacing Analysis

It is easy to visualize a decrease in the driveway accident rate when the spacing between adjacent driveways and/or the spacing between a driveway and the nearest intersection leg is increased. Holding constant the length of the section while increasing one or both of the driveway spacing variables can only lead to a decrease in the number of driveways. While this may seem very logical, the engineer has little in the way of facts he can present to verify or disprove this claim. The literature is in accord when they proclaim longer distances between adjacent driveways and between driveways and adjacent intersection

legs, but they based their findings on criteria other than the driveway accident rate. This phase of the analysis was developed to examine this relationship.

The method of analysis involved defining two average spacing variables, one denoting the average spacing between two adjacent driveways and the other denoting the average spacing between a driveway and an adjacent intersection leg, for each of the study sections. Throughout this analysis, both of these spacing variables were given in units of feet. The variables were then plotted against and correlated with the two driveway accident rates, as previously developed. Because each driveway accident rate was developed as a result of averaging a 3 year accident history, only 92 roadway sections were utilized in this analysis.

Development of Driveway Spacing Variables

Two driveway spacing variables were defined for each of the 92 study sections; the average spacing between two adjacent driveways, and the average spacing between a driveway and the nearest intersection leg. The term average spacing reflects the fact that the analysis is based upon roadway sections, and not upon a critical location where only one distance determines the spacing. Over a roadway section there are many instances where two driveways are adjacent and a driveway is adjacent to an intersection leg. All of these conditions were added up by category,

and divided by the number of times they occurred over a section to give the average spacing variables. This technique is explored in greater detail below.

Data for this section of the analysis were obtained by reproducing scaled maps of each roadway section from the measurements obtained when the sections were inventoried early in the data collection phase. The map was drawn to a vertical scale of 1 inch equals 100 feet, but a horizontal scale depicting the width of the section was not employed so as to accommodate the inclusion of the spacing variables. Figure 5 shows an example of a scaled map of section 21 in Marion, and it helps develop the procedure employed for selecting the driveway spacing variables. The map was drawn according to the scale indicated, and a straight line was drawn down the centerline of the section. A straight line was then drawn from the centerline of each driveway and intersection leg within the section (including both section terminals) to intersect at right angles with the line drawn down the centerline of the roadway section. Beginning at one of the section terminals, start to label the two variables; perhaps using D_j to denote an individual spacing between adjacent driveways and I_j to denote an individual spacing between a driveway and an adjacent intersection leg. Figure 5 indicates the proper location on the map for each of the variables. Utilizing this criterion, the average spacing between adjacent driveways was

FIGURE 5. DEVELOPING DRIVEWAY SPACING VARIABLES FROM SCALED MAP OF SECTION 21 (MARION)

FIGURE 5. (CONTINUED)

mathematically represented as follows:

$$\text{Average Driveway - Driveway Spacing} = \frac{\sum_{i=1}^m D_i}{m}$$

In a similar manner, the average spacing between a driveway and an adjacent intersection leg was mathematically represented as follows:

$$\text{Average Driveway - Intersection Spacing} = \frac{\sum_{j=1}^n I_j}{n}$$

Since the method employs spacing criteria based upon the driveway and intersection characteristics on both sides of the roadway section, care must be taken both in the field and in the office when analyzing two curb cuts which seem to be exactly opposite each other. Strict field procedures were necessary to ascertain whether a driveway was located exactly opposite another or was offset even a slight amount. Access points located exactly opposite each other were indicated in the roadway section map by having their centerlines come together from opposite sides of the road at the arterial centerline, such as in Figure 5 where the intersections Baldwin Avenue, Forest Avenue, Butler Avenue, and Park Avenue exemplify this procedure. In some cases, such as the spacings between the first two driveways on opposite sides of the road east of Geneva Avenue, the driveways were not quite opposite each other, and an offset had to be introduced. The importance of recognizing and correctly

labeling each offset cannot be overemphasized because of the effect they have been found to have on traffic flow when vehicles turning left into a driveway are involved.

The Relationship between Driveway Accident Rates and the Average Spacing over a

Section of Roadway between Adjacent Driveways

The initial step in this analysis was to plot the average spacing variable denoting the distance between adjacent driveways against its corresponding driveway accident rate for each of the 92 roadway sections. Two graphs resulted; one based upon the number of driveway accidents per mile per year, and the other based upon the number of driveway accidents per 100 million vehicle miles. Both graphs displayed such a scatter of points that useful, significant information could not be obtained. Furthermore, it was obvious from the arrangement of points that transformations on either variable would produce no better results than would the initially generated linear plot. From these results, there would seem to be no possible relationship between either of the two accident rates and the average spacing over a section of roadway between adjacent driveways.

In spite of these events, two additional methods of analysis were investigated. Because the linear plot seemed to be as good as any other that was generated, it was decided to fit the best possible straight line through the

data by utilizing the technique of least squares. Designating Y_1 as the number of driveway accidents per mile per year, Y_2 as the number of driveway accidents per 100 million vehicle miles, and X as the average spacing over a section of roadway between adjacent driveways, the following two regression equations were developed:

$$Y_1 = 7.72808 - 0.05470 X$$

$$Y_2 = 183.52598 - 0.99169 X$$

The multiple correlation coefficient (R^2) for the first was 0.02750, while for the second it was 0.02585, meaning that these two equations explain less than 3% of the variation in the driveway accident rate. While these low figures were anticipated, this method was attempted for the purpose of investigating the coefficient of X . In both cases the coefficient had a negative sign, indicating that the driveway accident rate decreases when the average spacing between adjacent driveways increases. The magnitude of R^2 permitted little else to be said regarding the equations.

The second method involved examining the simple correlation between each driveway accident rate and the variable denoting the average spacing between adjacent driveways. The simple correlation coefficient is a measure of the degree of association among variables. Values of the correlation coefficient range from +1 to -1, and there are 3

critical values to be recognized. A value of -1 represents perfect negative linear association between the two variables in the sample; a value of $+1$ represents perfect positive linear association in the sample; and a value of 0 is interpreted to mean that no linear association between the two variables exists in the sample (54). This is to say that a linear relationship between two variables decreases as the simple correlation coefficient decreases to zero from the positive or negative side.

Utilizing the same designation of terms as was made in the simple regression analysis, the correlation between Y_1 and X was -0.16582 , while the correlation between Y_2 and X was -0.16079 . The fact that both values were fairly close to zero substantiated the claim that the variables were not significantly related in a linear fashion. Of more importance was the negative sign preceding the correlation coefficients, indicating a trend toward decreasing driveway accident rates when the average spacing between adjacent driveways is increased. Results such as these should not be surprising in light of those obtained from simple regression analysis, because the simple correlation coefficient is actually the square root of the multiple correlation coefficient.

It is obvious that this method of analysis could disclose no significant relationship between the driveway accident rate (both rates seemed to produce approximately

the same results) and the average spacing between two adjacent driveways. However, there does appear to be a trend in which the driveway accident rate decreases when the average spacing between adjacent driveways increases.

The Relationship between Driveway Accident Rates and the Average Spacing over a Section of Roadway between A Driveway and an Adjacent Intersection Leg

The methods of analysis employed were very similar to those used in the previous section. The initial step involved formulating two graphs; plots of the average distance between a driveway and an adjacent intersection leg first against the number of driveway accidents per mile per year, and then against the number of driveway accidents per 100 million vehicle miles. As was the case in the previous analysis, both graphs displayed a scatter of points, from which no significant information could be gained. This scatter of points precluded the possibility of obtaining better results when transformations were made on one or all of the variables.

The method of least squares was introduced to fit the best possible straight line through the data. Designating Y_1 as the number of driveway accidents per mile per year, Y_2 as the number of driveway accidents per 100 million vehicle miles, and Z as the average spacing over a section of roadway between a driveway and an adjacent intersection leg, the following regression equations were developed:

$$Y_1 = 11.58371 - 0.06847 Z$$

$$Y_2 = 207.98228 - 0.79154 Z$$

The value of R^2 for the first equation was 0.10129, while for the second equation it was 0.03873. While both values are extremely small, it seems that better results were obtained when driveway accidents per mile per year, as opposed to driveway accidents per 100 million vehicle miles, was employed as the dependent variable. In any event, a regression equation that explains even 10.13% of the variation in the number of driveway accidents per mile per year is insignificant from an engineering viewpoint. However, some insight was gained by examining the coefficient of Z in both of the equations. Both of the coefficients were negative in sign, indicating that the driveway accident rate decreased when the average spacing between a driveway and an adjacent intersection leg increased.

Examination of the simple correlation between each driveway accident rate and the variable denoting the average spacing between a driveway and an adjacent intersection leg produced results similar to those obtained in the average spacing between adjacent driveways analysis. Utilizing the same designation of terms as was made in the simple regression analysis, the correlation between Y_1 and Z was -0.31826, while the correlation between Y_2 and Z was -0.19679. As expected, these results are in agreement with those

generated in simple regression analysis, with Y_1 seeming to have the stronger linear relationship of the two dependent variables with the driveway-intersection spacing variable. The negative signs preceding the correlation coefficients were indicative that the driveway accident rate decreased when the average spacing between a driveway and an adjacent intersection leg increased.

This method of analysis could disclose no significant relationship between the driveway accident rates (even though the number of driveway accidents per mile per year possessed a stronger linear association with the average spacing between the driveway and the intersection leg than did the number of driveway accidents per 100 million vehicle miles) and the average driveway-intersection spacing. However, as was the case in the analysis of driveway-driveway spacing, there appears to be a trend in which the driveway accident rate decreases when the average spacing between a driveway and an adjacent intersection leg increases.

The Relationship between Driveway Accident Rates and Roadway Characteristics

Analysis Techniques and Selection of Variables

This portion of the analysis was concerned with determining those roadway factors and/or combinations of roadway factors having the greatest effect upon the driveway accident rate. One method of establishing which of the variables, and their order of importance, has the greatest effect upon the driveway accident rate is multiple regression analysis. Multiple regression analysis is particularly valuable in cases such as this where the knowledge of more than one predictor variable (roadway factor) is necessary in order to obtain a better understanding and/or a better prediction of a particular response (the driveway accident rate). The multiple regression technique was employed for two general purposes in this study:

1. To develop an equation or series of equations which can be used to predict the driveway accident rate for a section of arterial highway based only upon the characteristics of the roadway and its abutting environment.
2. To determine the order of significance of each variable employed in all prediction equations.

Computer analysis was required to handle the anticipated large volume of data from the 92 test sections, and it was decided to employ a least squares technique known as stepwise multiple regression. A computer program employing

analysis by stepwise regression was acquired through the Purdue University Statistical Laboratory Library Program. Sometimes known as the "building up" method, stepwise regression adds predictor variables, one at a time, to the regression equation until the addition of another variable will add nothing significant to the ability of the regression equation to predict the dependent variable. The first variable introduced is that variable having the highest partial correlation with the dependent variable. The next variable to enter the equation is that predictor variable having the highest partial correlation with the dependent variable, given that the first predictor variable is already in the equation. Similarly, the third variable to enter the regression equation is that predictor variable having the highest partial correlation with the dependent variable, given that the first two predictor variables are already in the equation. This process continues until the variable list is exhausted, or until there remains no more significant independent variables to enter the regression equation. It is quite possible that the addition of a variable or a group of variables could reduce the significance of another variable already in the regression equation to the point where it no longer significantly contributes to the predictive equation. The computer program utilized in the analysis removed such variables at the proper time, but it permitted those initially rejected

variables to re-enter at a later step, if their significance could be re-established.

Stepwise multiple regression was used to develop separate equations for the two dependent variables, driveway accidents per mile per year and driveway accidents per 100 million vehicle miles, using as independent variables characteristics of the arterial highway and its abutting environment. At the outset of this study a list was made of every conceivable roadway factor that could possibly have an effect on the driveway accident rate. This list of roadway factors was gradually reduced when certain variables, such as one denoting the presence or absence of a median, were held constant for all 92 roadway sections, and when illogical results could be anticipated from the inclusion of a certain variable, such as one designating the arterial highway pavement condition. The analysis was begun utilizing 28 independent variables representing what was felt to be the 24 most important and most logical roadway factors. Table 8 gives a listing of the identifying index, name, and a description of the variables as they were coded for not only the 28 independent variables, but also for the two dependent variables. An indication of the characteristics of some selected variables is presented in Table 9. The indicated characteristics of each of the variables is based upon a sample size of 92 roadway sections.

Table 8. List of Variables.

Index	Variable Name	Description and Information Coded
Y ₁	Driveway Accidents Per Mile Per Year	
Y ₂	Driveway Accidents Per 100 Million Vehicle Miles	
X ₁	Urban Area Population/100,000	Urban area population in hundred thousands based upon 1970 Census
X ₂	1969 ADT/100,000	1969 Average Daily Traffic Volume in hundred thousands
X ₃	Street Type	Denotes whether the section is a 1 way or 2 way street One Way = 0 Two Way = 1
X ₄	Posted Speed Limit	Roadway Section Speed Limit
X ₅	Parking	Parking conditions denoted by dummy variables whose relationship is
X ₆	Parking	X ₅ X ₆ X ₇
X ₇	Parking	0 0 0 no parking 1 0 0 parking both sides 0 1 0 parking N. or E. side 0 0 1 parking S. or W. side
X ₈	Street Width	Curb to Curb width of roadway section
X ₉	Number of Through Lanes	Number of through traffic lanes on the arterial excluding width reserved for parking.
X ₁₀	Lane Markings	No Lane Markings = 0 Lane Markings (Visible) = 1

Table 8. Continued.

Index	Variable Name	Description and Information Coded
X ₁₁	Curbs	Curb conditions, denoted by dummy variables whose relationship is X ₁₁ X ₁₂ X ₁₃
X ₁₂	Curbs	
X ₁₃	Curbs	
		0 0 0 No curbs
		1 0 0 Curbs on Both Sides
		0 1 0 Curb on N. or E. side
		0 0 1 Curb on S. or W. side
X ₁₄	Stop signs and red flashers per mile	Number of stop signs and red flashers per mile.
X ₁₅	Traffic Signals per mile	Number of traffic signals per mile.
X ₁₆	Yield signs and amber flashers per mile	Number of yield signs and amber flashers per mile.
X ₁₇	3-way intersections per mile	Number of 3-way intersections per mile
X ₁₈	4-way intersections per mile	Number of 4-way intersections per mile
X ₁₉	Total intersections per mile	Number of total intersections per mile
X ₂₀	Alleys per mile	Number of alleys per mile
X ₂₁	Residential driveways per mile	Number of residential driveways per mile
X ₂₂	Commercial driveways per mile	Number of commercial driveways per mile
X ₂₃	Industrial driveways per mile	Number of industrial driveways per mile
X ₂₄	Other driveways per mile	Number of other driveways per mile
X ₂₅	Total driveways per mile	Number of total driveways per mile
X ₂₆	Friction points per mile	Number of friction points per mile
X ₂₇	Average spacing (ft.)	Driveway-Driveway both sides of road
X ₂₈	Average spacing (ft.)	Driveway-Intersection both sides of road

Table 9. Characteristics of Selected Independent and Dependent Variables.

Variable	Mean	Standard Deviation	Maximum	Minimum	Range
Y ₁	4.67	6.06	28.40	0.00	28.40
Y ₂	128.00	113.37	468.70	0.00	468.70
(100000) X ₁	120,794.36	207,021.76	744,624.00	31,403.00	713,221.00
(100000) X ₂	9,043.51	5,574.83	31,034.00	1,153.00	29,881.00
X ₈	34.46	8.33	50.00	20.00	30.00
X ₁₄	0.30	0.88	4.70	0.00	4.70
X ₁₅	1.68	2.18	11.70	0.00	11.70
X ₁₆	0.04	0.27	2.00	0.00	2.00
X ₁₇	5.19	4.32	16.80	0.00	16.80
X ₁₈	6.28	4.21	15.90	0.00	15.90
X ₁₉	11.53	4.12	23.60	2.70	20.90
X ₂₀	9.23	8.86	35.30	0.00	35.30
X ₂₁	30.18	23.13	109.10	0.00	109.10
X ₂₂	19.80	18.10	73.30	0.00	73.30
X ₂₃	2.26	4.53	26.80	0.00	26.80
X ₂₄	2.74	3.77	21.90	0.00	21.90
X ₂₅	64.20	19.73	119.30	25.90	93.40
X ₂₆	82.21	19.71	130.40	35.40	95.00
X ₂₇	55.99	18.38	133.30	25.20	108.10
X ₂₈	101.05	28.19	182.70	44.30	138.40

Initial Investigations

The stepwise regression computer program was used to develop two equations for the purpose of observing trends and gaining some insight as to the feasibility of this type of analysis. In developing regression equations to predict the number of driveway accidents per mile per year and the number of driveway accidents per 100 million vehicle miles it was decided to place conservative constraints on the program so that as many variables as possible would be allowed to enter the regression equations. By utilizing this procedure one maintains the advantage of not accidentally restricting a significant variable from entering the equation and of noting those variables that would have entered the equation had the constraints been slightly lowered. As a general rule, every variable that enters a regression equation effects an increase in the multiple correlation coefficient (R^2) by adding to the sum of squares due to regression. This multiple correlation coefficient ranges in value from zero to one, and the closer the value of R^2 is to one, the better will be the resulting regression equation. When considering independent variables to be included in the prediction equation, the resulting value of R^2 should not take precedence over the eventual ease of use of the equation. An equation which can relate the dependent variable to four independent variables with an R^2 of about 0.75 has more practical use to the engineer than one which can relate

the dependent variable to eleven independent variables with an R^2 of 0.80, because less effort is required to collect the data for four independent variables than for eleven. In the interests of saving time and resources one should include in a regression equation only those independent variables effecting a significant increase in R^2 . A test was conducted after each step to determine if the addition of that variable to the regression equation resulted in a significant increase in R^2 . For example, assume that the test revealed that the variable entering in step number 7 did not effect a significant increase in R^2 . Therefore, variables entering in steps one through six were included in the equation, while all others were deleted. The F-test utilized to determine at which step the increase in R^2 was no longer significant is stated mathematically as follows:

$$F = \frac{(R_j^2 - R_k^2)/(j - k)}{(1 - R_j^2)/(n - j - 1)} \quad \text{with } (j-k) \text{ and } (n-j-1) \text{ degrees of freedom.}$$

Where

F = the calculated F value.

R_j^2 = the multiple correlation coefficient when j independent variables are in the regression equation.

R_k^2 = the multiple correlation coefficient when k independent variables are in the regression equation.

n = the total number of observations ($n = 92$ in this study).

j = the number of independent variables in the regression equations to be tested for a significant increase in R^2 ($j = k+1$).

k = the number of independent variables in the regression equation used to base the significant increase in R^2 .

This calculated value of F was compared against a tabled value of F with $(j-k)$ and $(n-j-1)$ degrees of freedom. When the tabled F value exceeded the calculated F value, no significant increase in R^2 was experienced by adding the independent variable to the regression equation at that step. The significance level for this F test was set at the 0.05 level.

The regression equations developed for purposes of predicting the number of driveway accidents per mile per year and the number of driveway accidents per 100 million vehicle miles are as follows:

$$Y_1 = -3.64655 + 0.13252 X_{22} + 1.18792 X_9 - 0.27802 X_{19} \\ + 0.05012 X_{25} + 43.14119 X_2 - 0.82909 X_1$$

$$Y_2 = 91.16689 + 3.47978 X_{22} - 8.89195 X_{19} + 3.77002 X_{20} \\ + 51.28152 X_3$$

The order of the independent variables, as given in both equations, was the order into which they entered the regression equation. Table 10 is a listing of all significant variables to enter one or the other regression equation which shows the rank order in which the variables entered in both equations. It is interesting to note that, with the exception of X_2 and X_3 , every variable that was significant in one equation was either significant or marginal in the other. The discrepancy between the points of entry of X_2 can be explained by the fact that the 1969 ADT was used to compute the number of driveway accidents per 100 million vehicle miles, but no explanation is readily available for the behavior of X_3 . Overall it would seem that both equations predict the driveway accident rate utilizing practically the same independent variables.

However, the investigation of the respective multiple correlation coefficients is revealing. The value of R^2 associated with predicting the number of driveway accidents per mile per year (Y_1) is 0.7099, while that associated with predicting the number of driveway accidents per 100 million vehicle miles (Y_2) is only 0.4314. The situation exists where essentially the same independent variables are being used to predict two driveway accident rates with drastically different results. Since this analysis is being performed to develop some criteria upon which the driveway accident rate can be best predicted from the knowledge of

Table 10. Initial Analysis-Order of Entering Variables.

Independent Variable	Accidents/Mile/Year	Accidents/100 mvm
X_1	6	6
X_2	5	16
X_3	20	4
X_9	2	7
X_{19}	3	2
X_{20}	8	3
X_{22}	1	1
X_{25}	4	8

roadway factors, it would be best to utilize that expression for prediction which produces the best results. Driveway accidents per mile per year are obviously predicted significantly better than driveway accidents per 100 million vehicle miles, and analysis based upon Y_2 will be excluded from further development unless something can be done to effect a better multiple correlation coefficient.

Since the data itself could not be altered, the only alternatives were to transform the data by performing some mathematical function on the variables, or utilizing square and/or cross product terms of the significant independent variables. Transformations made on the dependent variable, such as taking the square root or the base 10 logarithm of Y_2 as the new dependent variable, produced insignificant changes in the value of R^2 when stepwise regression was performed. In fact, the value obtained for R^2 was lower when the square root of Y_2 was used as the dependent variable. The introduction of squares and cross products of the independent variables into the analysis had a similar effect. Every attempt to effect a substantial increase in the value of R^2 failed.

For predictive purposes, an equation that can explain almost 71% of the total variation in the dependent variable is far more reliable than one that can explain only a little over 43%. Since nothing could be done to make this latter value of R^2 more respectable, the development of an equation

to predict the number of driveway accidents per 100 million vehicle miles was dropped from further consideration in favor of devoting all efforts toward increasing on the already satisfactory R^2 of 71% associated with the prediction of the number of driveway accidents per mile per year.

Improving the Model

While attempts were made to justify the continuation of using the model developed to predict the number of driveway accidents per 100 million vehicle miles by attempting to improve its predictive powers, the model predicting the number of driveway accidents per mile per year was temporarily put aside. Examination of that particular model reveals some sound characteristics. The model relating six roadway factors to the number of driveway accidents per mile per year is reprinted as follows:

$$Y_1 = -3.64655 + 0.13252 X_{22} + 1.18792 X_9 - 0.27802 X_{19} \\ + 0.05012 X_{25} + 43.14119 X_2 - 0.82909 X_1$$

The value of R^2 associated with this model is 0.7099. This is to say that knowledge of the six independent variables on a section of arterial highway can be used to explain almost 71% of the variability in the number of driveway accidents per mile per year. This value of R^2 must be considered at least adequate, especially in the light of the fact that much of the variability in the driveway accident rate

must be attributed to human factors such as 'driver characteristics.

An examination of the arithmetic sign preceding each regression coefficient proved to be very informative. The signs were interpreted to read as follows:

1. The positive sign preceding X_{22} indicates that an increase in the number of commercial 'driveways per mile increases the number of driveway accidents per mile per year.

2. The positive sign preceding X_9 indicates that more driveway accidents per mile per year are experienced, on the average, as the number of through traffic lanes on the arterial highway is increased.

3. The negative sign preceding X_{19} indicates that the number of driveway accidents per mile per year will decrease with the introduction of more intersections per mile. This is probably due to the fact that every intersection leg effectively removes at least 50 feet of frontage on which no driveway can be introduced. Obviously the driveway accident rate declines with fewer driveways, but intersectional accidents will undoubtedly increase, and the effect may be a greater number of total traffic accidents on the arterial highway section.

4. The positive sign preceding X_{25} indicates that an increase in the total number of driveways per mile increases the number of driveway accidents per mile per year.

5. The positive sign preceding X_2 indicates that the number of driveway accidents per mile per year increases as the traffic volume on the arterial highway increases.

6. The negative sign preceding X_1 indicates that the number of driveway accidents per mile per year decreases as the size of the city increases. This fact is explained with the realization that more arterial highways are present in larger urban areas, and the drivers in larger cities are probably more used to driving on these type of facilities.

The stability of the model was further evidenced by the F value of 34.670 indicating the significance of the overall regression. While all signs point to the fact that this is a good model, it is by no means proof that it is the best model. This is the best model utilizing linear terms of all significant roadway factors, but it must be ascertained as to whether transformations or combinations of the six independent variables will produce a better model.

The first step in this search was to plot each of the independent variables against the dependent variable, driveway accidents per mile per year. The six graphs were examined for any possible deviation from linearity, and a list was made of the transformations that would possibly be significant. Based upon this graphical analysis it was decided to introduce the square of each of the six independent variables into the next stepwise regression program.

A product is evidence of interaction between two or more variables. The possibility of interactions occurring in this analysis was first brought to light when the driveway accident characteristics based upon significant data splits were examined. In this analysis it was discovered that the number of driveway accidents per mile increased as the number of lanes, the arterial highway ADT, and the number of commercial driveways per mile increased. The fact that these three independent variables, all of which were significant in the linear analysis, increased simultaneously with the dependent variable increases the possibility that the product of any two or all three together could be more significant than the main effect of the variables comprising the interaction.

Further evidence of possible interaction between independent variables was discovered through the use of the Automatic Interaction Detector (AID) computer program. This program examines all the independent variables and splits the sample into two groups by the independent variable that most sharply discriminates between values of the dependent variable. The procedure employed and the results obtained are best depicted with the aid of the flow chart, as given in Figure 6. Graphs of all 28 independent variables were made against the dependent variable, driveway accidents per mile per year, and each of the independent variables were split into groups based upon either a logical split, such

FIGURE 6. DETECTION OF INTERACTION BETWEEN ROADWAY CHARACTERISTICS

as one-way streets vs. two-way streets, or a split which would include an interval of the independent variable which would coincide with similar values of the dependent variable. For example, Table 11 shows the breakdown of data employed for commercial driveways per mile. Each interval of the independent variable is associated with an average value of the dependent variable which is representative of the sample within the interval. The analysis is interpreted by following, in sequence, the data splits employed. Each box in Figure 6 represents a data split, N is the sample size, $\bar{Y}$ is the average number of driveway accidents per mile per year for the N samples, and R is the range of the independent variable into which the data was separated. The first split was made on commercial driveways per mile into groups labeled 2 and 3. Group 2 contains that range of roadway sections, 72 in all, having less than 27 and between 34 and 42 commercial driveways per mile. These 72 sections averaged 2.472 driveway accidents per mile per year, as compared to the other 20 roadway sections which averaged 12.65 driveway accidents per mile. The splits continued, as diagrammed in Figure 6, in numerical order: group 3 splits on the basis of the number of three-way intersections per mile into group 4 and group 5; group 5 splits on the basis of urban area population into group 6 and group 7. This process continued until no more significant splits could be made. Missing group numbers in

Table 11. Splitting Commercial Driveways Per Mile Into Intervals for the Interaction Analysis.

Variable Range	Sample Size	Ave. Driveway Accidents Per Mile Per Year
Less than 1	13	1.308
1-3	4	0.000
4	6	1.333
5-8	7	2.571
9-13	8	2.250
14	3	6.667
15-27	26	3.154
28-33	9	9.556
34-42	5	3.000
43-60	7	11.000
Greater than 60	4	22.500

Figure 6, such as group 10 and group 11, indicate that a split was performed by the program, but was not graphically included because one of the new categories would have included less than 5 samples, a self imposed constraint. The majority of the samples were split into the left branch of the flow diagram, and it is in this direction to which attention is called. After the first split into groups 2 and 3, two data splits were made on the right branch before one was made on the left branch, indicating a tighter grouping between variables in the left branch in spite of the fact that it contains a larger number of samples. The first split in the left branch was made on the basis of arterial highway traffic volume, and one can see that 60 samples remain together in group 8 after two data splits were completed. The fact that almost two thirds of the samples remained together after attempts were made to split them on the basis of commercial driveways per mile and ADT indicates the possibility of an interaction between these variables. Other interactions are possible, but they were not examined because the main effects of the number of three-way intersections per mile and the average spacing between adjacent driveways proved to be very insignificant in the initial regression analysis. This analysis also upheld the significance of the number of commercial driveways per mile as a predictor of the number of driveway accidents per mile per year because of its early appearance in the

split. Another similar analysis was made using slightly different intervals in some of the independent variables, and the results showed the number of through traffic lanes to be not only a significant independent variable by itself, but also a possible interaction term with the number of commercial driveways per mile.

Three different approaches in the development of a better prediction model were analyzed. All three approaches involved the stepwise regression procedure, and included in the model only those variables and/or combination of variables whose presence in the model effected a significant increase in the value of R^2 . All transformations and interactions were formed using as a base only the six significant independent variables which appeared in the first model describing the number of driveway accidents per mile per year.

The first approach was to develop a model to predict the number of driveway accidents per mile per year on the basis of 22 independent variables, including all six main effect terms, the six squares of the main effect terms, five cross products involving two main effect variables each, four cross products involving three main effect variables each, and one variable denoting the number of commercial driveways per mile divided by the total number of driveways per mile. The cross product terms were developed on the basis of the order of entry of the six significant

main effect variables. Denoting the order of entry as 1, 2, 3, 4, 5, and 6, the cross products developed were (1)(2), (2)(3), (3)(4), (4)(5), (5)(6), (1)(2)(3), (2)(3)(4), (3)(4)(5), (4)(5)(6). This method was investigated to test the theory that the most significant interactions were formed by the variables that entered the regression equation adjacent to each other.

The second approach investigated the effect of all possible two way interactions together with the main effects and their squares. The analysis was based upon 27 independent variables, and it was hoped to be able to recognize the most important two way interactions in order of their occurrence.

The third approach was a variation of the second. The independent variables included the six main effects, their squares, the two way interactions which had a value of "F to remove" in the second approach greater than or equal to 1.00, and all possible three way interactions which could be formed by multiplying a main effect term by the two way interactions selected for use in this approach. A total of 36 independent variables was included for analysis in this study.

Stepwise regression analysis was performed on all three approaches, with only the independent variables effecting a significant increase in the value of R^2 being included in each model. Once it was decided which variables were significant in each of the three cases, those main

effect variables which did not enter in the stepwise regression procedure were introduced into the three equations, so that every regression equation took the general form:

$$Y = a + b + c + (a)(b) + (b)(c) + (a)(c)$$

This procedure of forcing insignificant independent variables into a regression equation was accomplished by means of the Multiple Regression computer program which performs a regression analysis only on the variables so indicated. The final models developed, then, were a mixture of the most significant interactions between independent variables and the main effect terms producing these interactions. The important point is that all three models were developed upon principles which were believed to produce the best possible model on the basis of the collected data.

In selecting which of the three models was best suited for purposes of best explaining the dependent variable, a number of criteria were investigated. The value of R^2 was important not only for purposes of comparison between the three models, but also as a factor in determining how much better or worse it is to utilize cross products and squares as opposed to the additive linear terms whose model produced an R^2 of 0.7099. For reasons of ease of use, it was desired to include as few terms as possible in the model, but this restriction carried less weight in this analysis, because only six different terms have to be evaluated, and

any increase in the number of terms was attributed to the inclusion of interaction terms and not to the inclusion of new main effect linear variables. Another criterion centered around the number of two way and three way interactions in the model because it is more difficult to physically explain the significance of a three way interaction than it is to explain a two way interaction. Likewise, it is more difficult to explain a two way interaction than a main effect term. Some characteristics of the three models are presented for comparison in Table 12. The first approach employed is designated as Model A; the second approach as Model B; the third approach as Model C; and the model developed utilizing only the main effect terms as Model D. The table of results clearly indicates the value of R^2 to be significantly better when interaction terms were included in the model as compared to when they were not. The highest value of R^2 is associated with that model, Model B, incorporating the largest number of significant independent variables. In fact, the value of R^2 seems to increase as the number of terms in the model increases. Another interesting comparison is the difference between the values of R^2 when the main effects are additive or multiplicative. The first term entered in Model A and Model B was the product of the number of commercial driveways per mile and the number of through traffic lanes producing an R^2 in both cases of 0.6131. The first two terms to enter Model D were the sum of these same two variables, producing an R^2 of

Table 12. Comparison between the Four Models Predicting Driveway Accidents Per Mile Per Year.

Model	R ²	F Value	Terms in Model				Total
			Main Effect	Main Effect ²	Two Way	Three Way	
A	0.8266	31.374	6	1	2	3	12
B	0.8452	27.6584	6	1	8	0	15
C	0.8131	31.6459	6	0	2	3	11
D	0.7099	34.670	6	0	0	0	6

0.5899. Likewise the first term entered in Model C was the three way interaction between the number of commercial driveways per mile, the number of through traffic lanes, and the number of total driveways per mile, producing a value of R^2 equal to 0.6459. The first three terms to enter Model D were the sum of these three variables, producing a value of R^2 equal to 0.6329. It would seem from these two examples that multiplicative combinations of the significant independent variables add more to the value of R^2 than do additive combinations of the same variables.

The model selected as the best was Model B. Even though more terms were involved in defining the model, the fact remains that only six independent variables need be measured and properly combined according to the interactions to explain 84.52% of the variation in the number of driveway accidents per mile per year. Model B was selected over Model A and Model C because of the total absence of three way interactions which are extremely difficult to physically explain. The F value for Model B, lower than that for any of the other models on account of the greater number of terms in the model, remained large enough to uphold the significance of the overall regression. The model, in its final form, can be written as follows:

$$\begin{aligned}
Y_1 = & -7.06689 + 0.29958 X_1 + 15.55023 X_2 + 2.24979 X_9 \\
& + 0.63574 X_{19} + 0.07498 X_{22} + 0.02382 X_{25} \\
& + 0.02371 X_9 X_{22} - 0.37175 X_9 X_{19} + 0.28006 X_2 X_{25} \\
& - 0.00925 X_1 X_{25} - 0.01045 X_{19} X_{22} + 0.06650 X_1 X_{19} \\
& - 8.06698 X_1 X_2 + 0.46140 X_9^2 + 0.92805 X_2 X_{22}
\end{aligned}$$

The order of the interaction and square terms in this model is that order in which they entered during the stepwise regression analysis. Such is not the case for the main effect terms, as they had to be forced into the model.

Evaluating and Testing the Model

Initial evaluation of the model revealed the overall regression to be significant, and the value of R^2 to be satisfactory. Additional investigations into the value of the model as an accurate predictor of the number of driveway accidents per mile per year included the examination of the residuals and an evaluation of the practicality of the arithmetic signs preceding the coefficients of the independent variables.

The residuals are the difference between the number of driveway accidents per mile per year actually occurring over the three year period and the number of driveway accidents per mile per year predicted by the model for each of the 92 roadway sections. Regression analysis was employed

under the assumption that these residuals are independent, have a mean equal to zero, possess a constant variance, and approximate a normal distribution. The residuals should exhibit tendencies that do not deny the validity of these assumptions if the fitted model is correct (21). By virtue of the fact that a constant term exists in the model, the sum, and therefore the mean, of the 92 residuals is zero. The assumption that the residuals should follow a normal distribution is examined in Figure 7, a plot of the frequency of residuals occurring at set intervals. While the plot can be said to exhibit a slight irregularity it does not seem to be far removed from that of a normal distribution. Homogeneity of variance was evaluated by examining a plot of the residuals against their respective $\hat{Y}_i$ as predicted from the regression equation. A plot of this type can be found in Figure 8. The plot is representative of a good scatter of points, which probably would take on more meaning if a greater number of points were available for higher values of $\hat{Y}_i$. Because no definite pattern was established, it was said that the initial assumption involving constant variance in the residuals was satisfied, and that the model required no additional terms to improve its effectiveness as a predictor. The residuals ranged from a low value of -6.671 driveway accidents per mile per year to a high value of 7.516 driveway accidents per mile per year, for a range of 14.178 driveway accidents per mile per year. A small range in residuals, such as that obtained

FIGURE 7. FREQUENCY OF RESIDUALS

FIGURE 8. PLOT OF RESIDUALS vs. $\hat{Y}_i$

for this model, is desired because it indicates that the model's predictions of the dependent variable closely resemble the actual conditions. The standard error of the mean for this sample of 92 residuals was 2.61 driveway accidents per mile per year. These characteristics of the residuals have indicated the fitted model to be adequate and not lacking in any terms.

The arithmetic signs preceding the coefficients of the independent variables reveal much about the practicality of the model. For example, if every previous study indicated that the number of driveway accidents per mile per year increases as the number of commercial driveways per mile increases, one would expect to find a positive sign preceding the coefficient of the independent variable representing the number of commercial driveways per mile. In any event, the arithmetic sign must be logically explained for every term in the model before the model is accepted as being useful. The sign convention in the strictly linear model was not only easy to explain, but the sign convention employed for every independent variable seemed logical. However, the task is not so easy when trying to explain the sign convention in the model containing interactions, because the same variable is liable to appear in two or more terms in the model with the result being that the arithmetic sign must be evaluated not only on the basis of the signs preceding the main effect term,

but also on the basis of the signs of all other variables containing that term. To further complicate the procedure is the fact that the sign is also dependent upon the magnitude, for a particular case, of the variable which is multiplied by the variable about which it is desired to evaluate the sign. An example of this situation is found by evaluating the sign preceding X_{25} , the total number of driveways per mile, in the model containing interactions. It can be shown algebraically, that the sign is determined by evaluating the coefficient of X_{25} as being:

$$(0.02382 + 0.28006 X_2 - 0.00925 X_1)$$

The three terms in parentheses are those terms by which X_{25} was multiplied in the regression equation. It can easily be seen that the sign is determined, in this case, by both the ADT and the population, and that the sign could conceivably vary from case to case from positive to negative under the proper conditions. For this reason it is mandatory that the determination of all signs be made only within the limits of the data used to develop the coefficients, as given in Table 9.

The magnitude of the coefficient of any independent variable is the rate of change which a one unit deviation in that independent variable will have upon the dependent variable, when all other effects are held constant. As an example, the coefficient of X_{22} , the number of commercial

driveways per mile, in the six term linear model is $+ 0.13252$. Holding the other four terms in the equation constant, it is evident that an increase of one commercial driveway per mile will, on the average, effect an increase of approximately 0.13 driveway accidents per mile per year. Once again, this type of analysis presents no problems when only main effect terms are present in the model. In applying this type of analysis to the model containing interaction terms, the same problem arises as was experienced in developing an accurate sign convention for the independent variables. Both the coefficient and the sign are dependent upon so many factors that it would be unreasonable to print all possible combinations. As a result, a sensitivity analysis was undertaken on three of the coefficients to determine how different sections of arterial highway affect the driveway accident rate in different ways. The engineer, generally, would be concerned about a section of highway with a high driveway accident rate more than he would about a section with a low driveway accident rate. As a result, it was decided to test the sensitivity of the coefficients on the 10 roadway sections out of the 92 with the highest number of driveway accidents per mile per year. The three independent variables selected for this study include the number of commercial driveways per mile, the total number of intersections per mile, and the total number of driveways per mile. It was believed that the engineer would

have the easiest time altering any one of these three variables, as opposed to the ADT, population, or number of lanes, to effect a change in the number of driveway accidents per mile per year.

The first step involved isolating the coefficients of the three independent variables. It can be shown that the coefficient of X_{22} , the number of commercial driveways per mile, is $0.07498 + 0.02371 X_9 - 0.01045 X_{19} + 0.92805 X_2$; that the coefficient of X_{25} , the number of total driveways per mile, is $0.02382 + 0.28006 X_2 - 0.00925 X_1$; and that the coefficient of X_{19} , the number of total intersections per mile, is $0.63574 - 0.37175 X_9 - 0.01045 X_{22} + 0.06650 X_1$. The magnitude and sign of each coefficient were determined by inserting into each coefficient relationship the appropriate value of the independent variable corresponding to a given roadway section. Table 13, Table 14, and Table 15 indicate the results of the analysis, and it will be noted that the roadway sections are arranged in decreasing order of the number of driveway accidents per mile per year.

An examination of Table 13 reveals that the ten sections all have a negative coefficient associated with the total number of intersections per mile. Everything else being held constant, this is to say that increasing the number of intersections per mile on a section of arterial highway resulted in a decrease in the number of driveway accidents per mile per year. The magnitude of the

Table 13. Variations in the Coefficient of X_{19} , the Total Number of Intersections Per Mile, for Ten High Driveway Accident Sections.

Section	Coefficient
56	- 1.53678
47	- 1.14591
19	- 1.54511
50	- 0.70023
37	- 1.57131
76	- 0.36955
7	- 1.14183
2	- 0.95686
74	- 0.62349
11	- 1.40717

Table 14. Variations in the Coefficient of X_{22} , the Number of Commercial Driveways Per Mile, for Ten High Driveway Accident Sections.

Section	Coefficient
56	+ 0.25789
47	+ 0.24394
19	+ 0.22167
50	+ 0.16831
37	+ 0.11186
76	+ 0.18869
7	+ 0.18313
2	+ 0.23735
74	+ 0.13845
11	+ 0.13382

Table 15. Variations in the Coefficient of X_{25} , the Total Number of Driveways Per Mile, for Ten High Driveway Accident Sections.

Section	Coefficient
56	+ 0.07030
47	+ 0.05856
19	+ 0.07103
50	+ 0.07118
37	+ 0.06388
76	+ 0.05592
7	+ 0.05153
2	+ 0.05749
74	+ 0.06252
11	+ 0.06281

coefficient, as was previously noted, is the rate of change which a one unit deviation in the number of intersections per mile will have on the number of driveway accidents per mile per year. On section 56, for example, the deletion of one intersection per mile effects an annual increase of almost 1.54 driveway accidents per mile. On the average, the removal of one intersection per mile effected an increase of between 0.370 and 1.571 driveway accidents per mile per year on the ten high driveway accident sections.

The positive signs associated with the coefficients of the number of commercial driveways per mile indicate an increase in the number of driveway accidents per mile per year as the number of commercial driveways per mile was increased. It was also evident from Table 14 that an increase of one commercial driveway per mile, on the average, effected an increase of between 0.112 and 0.258 driveway accidents per mile per year on the ten high driveway accident sections.

It can be seen in Table 15 that an increase in the total number of driveways per mile led, on the average, to an increase in the number of driveway accidents per mile per year. The magnitude of this increase is not as great, however, as that associated with the number of commercial driveways per mile, as evidenced by the fact that the removal of one driveway per mile of any type, on the average, effected a decrease of between 0.051 and 0.071 driveway accidents

per mile per year. While it is a fact that the total number of driveways per mile has a significant effect upon the number of driveway accidents per mile per year, this serves as further proof that the number of commercial driveways per mile is the most significant of the driveway variables.

The overall sign convention for the other three independent variables is the same as when the main effects were considered in a separate model by themselves. The number of driveway accidents per mile per year will decrease with a decrease in ADT, with an increase in urban area population, or with a decrease in the number of through traffic lanes.

This analysis could conceivably be used by engineers as a basis for warranting highway improvements or access control measures to curtail a high or rising number of driveway accidents per mile per year. It is obvious that one cannot easily remove a lane of traffic, sharply reduce the ADT, or relocate the arterial highway in an urban area of higher population to meet his goals. The addition of intersections to the arterial may present a remotely feasible solution, but the engineer must then be prepared to deal with an almost guaranteed increase in the number on non driveway accidents. The most feasible solution, therefore, would seem to be to effect a reduction in the number of driveways, particularly commercial driveways. One should also recall the interactions between the variables, and the

fact that a reduction in the number of commercial driveways should have an effect upon reducing the ADT on the arterial highway. These "side effects" only serve to increase the significance of the rate of change that the elimination of one driveway will have on the number of driveway accidents per mile per year.

The testing of the model was accomplished by using the model to predict the number of driveway accidents per mile that would occur on each of the 92 roadway sections during the year 1971. Since the model predicts the annual driveway accident rate, this was believed to constitute a valid test. Each of the predicted values would then be compared against the actual number of 1971 driveway accidents per mile for each of the sections, as collected and computed during the data collection phase. It was assumed that the population would remain relatively constant from 1969 to 1971 for each of the cities, and by virtue of the constraints imposed early in the data collection phase, the number of through traffic lanes, the total number of intersections per mile, the number of commercial driveways per mile, and the total number of driveways per mile were the same in 1969, the base year upon which the model was developed, and 1971. Only the ADT was altered to account for the difference in time, and the 1971 ADT's for all sections were calculated on the basis of the annual 4% compounded increase and utilized as such for prediction.

A computer program, entitled YHAT, was obtained through the Purdue University Statistical Laboratory Library. The printout included a listing of the actual number of 1971 driveway accidents per mile, the predicted number of 1971 driveway accidents per mile, and the difference between these two numbers for each of the 92 cases. With this information it was possible to tell how well the model predicts the number of 1971 driveway accidents per mile by developing a multiple correlation coefficient (R^2).

The value of R^2 is given by the expression:

$$R^2 = 1 - \frac{\sum_{i=1}^{92} (Y_{1i} - \hat{Y}_i)^2}{\sum_{i=1}^{92} (Y_{1i} - \bar{Y}_1)^2}$$

Where

Y_{1i} = the number of driveway accidents per mile occurring in 1971 on section i.

$\hat{Y}_i$ = the number of driveway accidents per mile predicted for 1971 on section i.

$\bar{Y}_1$ = the average number of driveway accidents occurring over all roadway sections in 1971.

The value of R^2 was computed to be 0.5269. This indicates that while the regression equation explains 84.52% of the variation in the number of driveway accidents per mile per year based upon the annual average of the 1968-1970 accident data, it can only explain 52.69% of the variation in the number of 1971 driveway accidents per mile. The reason

for this discrepancy can be traced to the methods employed in developing the accident rates earlier in the study. It is recalled that only 92 roadway sections were employed in the majority of the analyses because statistical tests revealed only these 92 out of 100 sections to possess a three year accident history that originated from the same population. However, it is possible that the number of 1971 driveway accidents per mile for a given section does not agree with its corresponding 1968-1970 averaged number of driveway accidents per mile. The situation exists where a model developed on the basis of the annual average of a three year driveway accident history is being used to predict the number of driveway accidents per mile for a one year period. Better results would have been obtained had the number of driveway accidents per mile for each section been proven to have originated from the same population. There were only about six cases where this rule was obviously violated, and the effect was indicated in the value of R^2 .

The correlation between the actual number of driveway accidents per mile and the predicted number of driveway accidents per mile was 0.7461. The difference between the actual and the predicted number of driveway accidents per mile varied from 19.7569 to -13.3551 for a range of 33.1120 driveway accidents per mile. This high range was attributed to the inclusion of those sections in which the 1971 accident data was substantially out of agreement with the three year history used to develop the model.

Care must be exercised when utilizing this model to consider only sections of arterial highway whose characteristics fall within the range of the data used to develop the model. Table 16 is a listing of the variable ranges employed in the development of the model for the six main effect terms and for the number of driveway accidents per mile per year. For example, this model should not be used to predict the number of driveway accidents per mile per year on a section of arterial highway having an ADT greater than 31,034 vehicles per day, as this is the upper limit of the range of ADT. A clearer picture exists when a hypothetical case is introduced on which values of the six main effect independent variables are equal to zero. Utilization of the model under such circumstances will produce a negative number of driveway accidents per mile per year. In defense of the model, however, it is felt that a wide enough range in each of the independent variables is available to insure analysis with this model on a large number of urban arterial highways.

Table 16. Range of Significant Variables.

Variable	Maximum	Minimum	Range
y_1	28.40	0.00	28.40
$100000(x_1)$	744624.00	31403.00	713221.00
$100000(x_2)$	31034.00	1153.00	29881.00
x_9	4.00	1.00	3.00
x_{19}	23.60	2.70	20.90
x_{22}	73.30	0.00	73.30
x_{25}	119.30	25.90	93.40

SUMMARY OF RESULTS

The significant results of this study can be summarized as follows.

Driveway Accident Characteristics

1. Driveway accidents represented 13.95% of all traffic accidents on the 100 selected arterial highway sections in central Indiana urban centers.

2. The fewest number of driveway accidents occurred on Sundays, 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. No significant difference in driveway accident occurrence by month of year could be established.

3. There were no recorded fatalities resulting from driveway accidents over the four year period of the study. 85.56% of the driveway accidents resulted in property damage only, while the remainder involved some kind of personal injury.

4. Left turn movements, to or from a driveway, resulted in 64.60% of all driveway accidents. 76.00% of all

driveway accidents resulting in personal injury involved a left turn maneuver.

5. 53.47% of the driveway accidents involved a vehicle entering a driveway, and 46.53% involved a vehicle exiting a driveway.

6. Obscured vision was found to be significant in only 13.53% of all reported driveway accidents. Only 1.57% of all driveway accidents could be traced to a malfunction of the driveway vehicle.

7. 60.07% of the driveway accidents were of the right angle variety, while 33.09% involved a rear end collision.

8. Driveway vehicles were struck by through traffic vehicles in 57.01% of the cases, whereas they struck the through vehicle in 33.34% of the cases. The driveway vehicle was not directly involved in the accident contact in 9.35% of the cases.

9. 72.28% of the driveway accidents occurred during daylight hours; 75.00% of the driveway accidents occurred during periods of non-precipitation; and 70.05% of the driveway accidents occurred under dry pavement conditions.

10. Over a four year period, two-way streets experienced almost 2.75 times the number of driveway accidents per mile than did one-way streets (23.843 to 8.761).

Driveway accidents on one-way streets represented only 6.37% of the total one-way street accidents, while on two-way streets they represented 16.35% of the total. The

average ADT for the 29 one-way street sections was found to be 7582 vehicles per day, while the volume was 9905 vehicles per day averaged over the 71 two-way street sections. Two-way streets averaged 21.32 commercial driveways per mile, while the one-way street sections averaged 16.20 commercial driveways per mile.

11. Over a four year period, the number of driveway accidents per mile, on the average, increased as the number of through traffic lanes on the arterial highway increased, as the number of commercial driveways per mile increased, and as the ADT on the arterial highway section increased.

Driveway-Driveway Spacing

1. Graphs of both driveway accident rates plotted against the variable denoting the average spacing between adjacent driveways produced a scatter of points from which significant information could not be derived.

2. The correlation between the number of driveway accidents per mile per year and the average spacing between two adjacent driveways was -0.16582. The correlation between the number of driveway accidents per 100 million vehicle miles and the average spacing between adjacent driveways was -0.16079.

Driveway-Intersection Spacing

1. Graphs of both driveway accident rates plotted against the variable denoting the average spacing between

a driveway and an adjacent intersection leg produced a scatter of points from which significant information could not be derived.

2. The correlation between the number of driveway accidents per mile per year and the average spacing between a driveway and an adjacent intersection leg was -0.31826. The correlation between the number of driveway accidents per 100 million vehicle miles and the average spacing between a driveway and an adjacent intersection leg was -0.19679.

The Relationship between Driveway Accident Rates and Roadway Characteristics

1. The stepwise multiple regression procedure was employed to develop one equation for each of the two dependent variables, the number of driveway accidents per mile per year (Y_1) and the number of driveway accidents per 100 million vehicle miles (Y_2). These two equations, with their respective values of R^2 , are given as follows:

$$\begin{aligned}
 Y_1 = & -3.64655 + 0.13252 \text{ (commercial driveways per mile)} \\
 & + 1.18792 \text{ (number of lanes)} - 0.27802 \text{ (total inter-} \\
 & \text{sections per mile)} + 0.05012 \text{ (total driveways per mile)} \\
 & + 43.14119 \text{ (ADT/100,000)} - 0.83909 \text{ (population/100,000)} \\
 & (R^2 = 0.7099)
 \end{aligned}$$

$$\begin{aligned}
 Y_2 = & 91.16689 + 3.47978 \text{ (commercial driveways per mile)} \\
 & - 8.89195 \text{ (total intersections per mile)} \\
 & + 3.77002 \text{ (alleys per mile)} + 51.28152 \text{ (street type)} \\
 & (R^2 = 0.4314)
 \end{aligned}$$

The differences in the value of R^2 and the inability to increase the value of R^2 of that equation relating the roadway factors to the number of driveway accidents per 100 million vehicle miles resulted in the elimination of that model from further consideration.

2. The model relating the number of driveway accidents per mile per year to the roadway factors was improved with the introduction of significant square and cross product terms involving the six significant main effect terms generated in the first model. The model, in its final form, reads as follows:

$$\begin{aligned}
 Y_1 = & -7.06689 + 0.29958 \text{ (population/100,000)} + 15.55023 \\
 & \text{(ADT/100,000)} + 2.24979 \text{ (number of lanes)} + 0.63574 \\
 & \text{(total intersections per mile)} + 0.07498 \text{ (commercial} \\
 & \text{driveways per mile)} + 0.02382 \text{ (total driveways per mile)} \\
 & + 0.02371 \text{ (number of lanes)(commercial driveways per} \\
 & \text{mile)} - 0.37175 \text{ (number of lanes)(total intersections} \\
 & \text{per mile)} + 0.28006 \text{ (ADT/100,000)(total driveways per} \\
 & \text{mile)} - 0.00925 \text{ (population/100,000)(total driveways} \\
 & \text{per mile)} - 0.01045 \text{ (total intersections per mile)} \\
 & \text{(commercial driveways per mile)} + 0.06650 \text{ (population/}
 \end{aligned}$$

$$\begin{aligned}
 &100,000)(\text{total intersections per mile}) - 8.06698 \\
 &(\text{population}/100,000)(\text{ADT}/100,000) + 0.46140 (\text{number} \\
 &\text{of lanes})^2 + 0.92805 (\text{ADT}/100,000)(\text{commercial drive-} \\
 &\text{ways per mile}) \qquad \qquad \qquad (R^2 = 0.8452)
 \end{aligned}$$

The order of the interaction terms and the square term in the model is the order of significance of the independent variables. The six main effect terms were forced into the model, and their order in the model, as listed, in no way reflects their relative importance.

3. The model was evaluated on the basis of the behavior of the residuals and the sign convention employed with the coefficients of the independent variables, and the results of both substantiated the significance of the model. The residuals satisfactorily passed the required statistical tests, and the arithmetic signs preceding the coefficients proved to be both logical and correct.

4. By evaluating the coefficients of the independent variables in the model with the square and interaction terms, the following facts were revealed about those 10 roadway sections with the highest number of driveway accidents per mile per year.

- a. On the average, the removal of one intersection per mile effected an increase of between 0.370 and 1.571 driveway accidents per mile per year on the 10 high driveway accident sections.

- b. The deletion of one commercial driveway per mile, on the average, effected a decrease of between 0.112 and 0.258 driveway accidents per mile per year on the 10 high driveway accident sections.
- c. The removal of one driveway per mile of any type, on the average, effected a decrease of between 0.051 and 0.071 driveway accidents per mile per year on the 10 high driveway accident sections.

5. When the model was tested against 1971 accident data, it was found that the regression equation explained 52.69% of the variation in the number of 1971 driveway accidents per mile. However, this was the result of utilizing an accident rate based upon one year of accident experience to test a model developed from an accident rate based upon a three year accident history.

CONCLUSIONS

The following conclusions concerning driveways and driveway accidents on urban arterial highways in central Indiana are presented.

1. Driveway accidents were found to represent a significant percentage of the total traffic accident experience on urban arterial highways, and steps taken to effect their decrease would lead to an improvement in overall highway safety.

2. There exists a trend in which the driveway accident rate is found to decrease when the average spacing over a section of arterial highway between adjacent driveways increases.

3. There exists a trend in which the driveway accident rate is found to decrease when the average spacing over a section of arterial highway between a driveway and an adjacent intersection leg increases.

4. Roadway factors can be used to predict the number of driveway accidents per mile per year significantly better than the number of driveway accidents per 100 million vehicle miles.

5. 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.

The order of occurrence of these conditions is the decreasing order of significance they have on the number of driveway accidents per mile per year. Furthermore, the urban area population, as a control variable used to effect a change in the number of driveway accidents per mile per year, is difficult to alter.

6. The interaction, or product, of two variables proved to be more significant, in every case, than the sum of the same two variables when predicting the number of driveway accidents per mile per year.

7. The practical applications of this research are many in number. The engineer can use the model not only to predict a future driveway accident rate, but he can present facts defending his decisions to reduce the number of access points for the public well being. Used within the

constraints from which it was developed, the model can be a valuable tool to all public officials concerned with the number of driveway accidents in their cities.

RECOMMENDATIONS FOR FURTHER RESEARCH

1. The model developed in this study can be used on a wide variety of arterial highways. Perhaps it would be better in the future to develop similar models based upon smaller data categories. For example, a model explaining the driveway accident rate for one-way streets, two lane highways, or residential as opposed to commercial areas may be of more benefit than one consolidating the characteristics of all. This idea certainly warrants more consideration.

2. If enough samples can be collected, the results of this study should be compared to a similar study involving arterial highways with barrier medians.

3. The model should be applied to urban areas in other sections of the country to test its effectiveness outside Indiana. If this is not possible, further testing of the model can be sustained in two ways:

- a. Devise a three year accident history from 1971, 1972, and 1973 accident records for the 92 study sections and test the model using the same procedures offered in this text.
- b. Collect a number of other study sections from the same cities, use the roadway data to predict an accident rate from the model, and compare the results with the actual figure.

4. The study of the relationship between the driveway accident rate and the spacing between a driveway and an adjacent intersection leg might best be performed at individual intersections, rather than over a section of highway. It is believed that better results could be produced when the critical intersections which lend themselves to a driveway accidents are examined on an individual and a collected basis.

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APPENDICES

Appendix A

ROADWAY DATA INVENTORY FORM

Section Number _____

City _____

Urban Area Population _____ (1970 Census)

Street Name _____

Section Terminals _____ To _____

Section Length _____ Feet _____ Miles

Posted Speed Limit _____ Miles Per Hour

Section Direction North - South _____ East - West _____

Street Operation One-way _____ Two-Way _____

Parking None _____ Both Sides _____ One Side _____ NSEW
Type (Parallel, Angle, etc.) _____

Number of Through Lanes N E _____
S W _____

Lane Markings Yes _____ No _____

Pavement Surface Type _____
Condition _____

Curbs None _____ Both Sides _____ One Side _____ NSEW

Shoulders None _____
Both Sides _____ Width _____ Feet
One Side _____ NSEW Width _____ Feet

Figure A1. Roadway Data Inventory Form.

Appendix B

DRIVEWAY ACCIDENT QUESTIONNAIRE

Section Number _____

Accident Number _____

Driveway Data

Land Use Type Served _____

Location : Driveway on _____ Side of Road.

Traffic Control Device: No _____ Yes _____ Type _____

Accident Location

At _____ Driveway.

Or _____ Feet N S E W of Intersection With _____

Accident Occured : 1) At Driveway _____

2) _____ Feet N S E W of Driveway.

Accident Severity

Fatality _____

Personal Injury _____

Property Damage _____

Time of Accident

Date _____

Day of Week _____

Time of Day _____ AM

_____ PM

Lighting

Daylight _____

Dark _____

Dawn _____

Dusk _____

Roadway Pavement Condition

Dry _____

Wet _____

Snow or ice _____

Other _____

Weather

Clear _____

Rain _____

Snow _____

Fog _____

Other _____

Figure B1. Driveway Accident Questionnaire (Side One).

Accident Cause

Vision Obscured Yes _____ No _____ By _____

Vehicle Defect Yes _____ No _____ What _____

Driveway Vehicle Ingress _____ Egress _____

Driveway Vehicle Struck _____ Was Struck _____ No Contact _____

Accident Type

Rear End _____

Right Angle _____

Head On _____

Sideswipe _____

Other _____ Specify _____

Diagram Of Accident

Figure B2. Driveway Accident Questionnaire (Side Two).