Evaluation of Factors Influencing Driveway Accidents

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Full control of access will obviously not lower the number of accidents that occur on urban arterial highways. Both land access and traffic movement must be allowed on this type of facility, so the causes of resulting traffic accidents must be identified, and deficiencies must be corrected. The literature contains much on intersection accidents, but relatively little has been written to identify the major causes of driveway-related traffic accidents, which account for almost 14 percent of total arterial highway traffic accidents. This paper identifies some of the characteristics of driveway accidents and relates driveway accident occurrence to various physical and environmental features of the roadway and traffic characteristics. Through statistical analysis, it is shown that the driveway accident rate tends to decrease as the spacing between two driveways and the spacing between a driveway and an adjacent intersection increase. Multiple regression analysis was used to develop a series of mathematical models relating the driveway accident rate to the physical and environmental features of the roadway and traffic characteristics. This procedure reveals that the driveway accident rate decreases as the number of commercial driveways per kilometer decreases, as the number of through-traffic lanes decreases, as the number of total intersections per kilometer increases, as the number of total driveways per kilometer decreases, or as the traffic volume on the arterial highway decreases. The results of this study provide the engineer or public official with tools to better identify the circumstances related to driveway accidents, to predict driveway accident rates, and to estimate the effectiveness of measures to reduce such accidents.

Reducing traffic accidents is and always will be one of the primary objectives of the highway engineer. The introduction of full control of access, which has been hailed as the most significant factor in accident reduction developed thus far (2), was designed to meet that objective. However, full control of access cannot be used as a sole solution to the accident problem because a complete highway system must provide both land access and traffic movement (4). The accident problem is further complicated on those facilities where these two functions must be simultaneously coordinated without delegating an advantage to either. A case in point is the urban arterial highway, which must encourage efficient through-traffic movement and provide access for abutting landowners.

Landowners access the arterial highway by means of driveways, each of which introduces an additional conflict to through traffic. As the number of such conflict points along an arterial highway increases, the opportunity for driveway-related traffic accidents increases. A driveway accident is a traffic accident in which at least one of the participants was moving to or from a driveway at the time of the accident or an accident resulting from such a movement.

The number of a particular type of accident on an arterial highway can be reduced only after the major factors contributing to its occurrence have been identified. Many studies have been conducted to mathematically identify causative factors of accidents at intersections, but relatively little has been written to identify the major contributors to driveway accidents. Driveway accidents represent a significant percentage of total arterial highway traffic accidents, as revealed in a recent study made in Skokie, Illinois, which found that driveway accidents composed 12 percent of that city's major street accidents (1). Because there is little reason to doubt that this figure is representative of urban arterial highway accident experience throughout the country, research directed toward a better understanding of the factors causing driveway accidents on urban arterial highways is of obvious benefit.

This research was developed to provide a means for improving overall highway safety and to expand on the limited existing data on driveway accidents. A literature search disclosed numerous voids and some conflicts of opinion on the subjects of driveways and driveway accidents (3). Given these observations, the following research objectives were developed:

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

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4. Relate driveway accident rates to characteristics of the roadway and its abutting environment and to traffic characteristics.

DATA COLLECTION TECHNIQUES

Relevant data obtained from 100 sections of urban arterial highway were analyzed. Ten roadway sections were taken from each of 10 central Indiana cities whose population exceeded 30 000. Three specific types of roadway data were collected: physical roadway, traffic volume, and traffic accident data.

Data on roadway characteristics were obtained by traveling to each site and inventorying all existing physical features of each roadway. A measuring wheel was used on both sides of every section to obtain an accurate measurement of all access and intersection spacing details. However, because many factors could conceivably influence the driveway accident rate, homogeneity with respect to certain variables throughout the length of each study section was mandatory. Therefore, sections selected for study had to meet the following criteria:

1. Curb parking characteristics must remain constant;
2. Curb-to-curb street width must remain constant;
3. No type of median divider can be present;
4. No major changes in traffic volume may occur between the termini of each section;
5. No major construction must have occurred on the section or on land abutting the section later than 1 year before the study (1968); and
6. Each section selected for study must be located outside the limits of the central business district but within the city limits.

Driveway types were classified into four categories: residential, commercial, industrial, and other. The first three classes refer to the principal land use served by the driveway; the fourth includes driveways to land uses other than the first three categories, such as fire houses, schools, and churches.

Most of the traffic volume data were obtained from state and local highway and planning officials. However, 19 percent of the data was collected by placing traffic counters at representative locations within each section. In all cases, however, pertinent traffic volume expansion factors and a 4 percent annual increase in traffic volume were used to obtain the average daily traffic (ADT) volume for each roadway section for each required study year.

Traffic accident data were collected for each of the 100 roadway sections for the period January 1, 1968, to December 31, 1971, from the standard accident report form as filed by the investigating police officer. Pertinent data on each driveway accident were transferred from the report to a preprepared form.

The methods of analysis determined how the data would be refined for study. To identify driveway accident characteristics, the first objective of this study, required the entire 4-year accident history of each roadway section. No special treatment of the data was necessary. The next three objectives, however, required the development of accident rates to be mathematically related in multiple regression analysis to particular characteristics of the study sections. Two accident rates, accidents/1.6 km/year and accidents/160 million vehicle-km, were developed (the latter rate was discarded early in the analysis because it did not relate so well to the roadway characteristics as did the accidents/1.6 km/year). A 3-year annual average of the 1968-1970 accident data was used to develop the accident rates used in multiple regression analysis. A chi-square goodness-of-fit test was applied to data from each of the 100 sections to test the hypothesis that the 3 years of accident data originated from the same population. Inasmuch as all but eight of the sections passed the test and it was determined in initial analyses that more statistically reliable results could be obtained without those eight sections, only 92 roadway sections were selected for analysis and used for the latter three study objectives. The accident rates used in testing the resulting regression equations were developed from 1971 accident data.

ANALYSIS OF DATA

Driveway Accident Characteristics

All 100 Roadway Sections

The 4-year accident history of 100 central Indiana urban arterial highway sections totaling 96.853 km (60.436 miles) in length revealed a total of 1212 driveway accidents. This represented 13.95 percent of all reported traffic accidents on these same roadway sections.

The following results were obtained when similar characteristics of each of the 1212 driveway accidents were grouped together:

1. The fewest number of driveway accidents occurred on Sunday when traffic volumes are lowest and when most business establishments are closed. A higher number was experienced on Friday and Saturday when traffic volumes are heavier and when more trips to commercial establishments, on the average, occur. The following figures show the number of driveway accidents and the percentage of the total number of driveway accidents that occurred each day.

Day	Number	Percentage of Total	Day	Number	Percentage of Total
Sunday	92	7.59	Thursday	188	15.51
Monday	166	13.70	Friday	255	21.04
Tuesday	146	12.05	Saturday	233	19.22
Wednesday	132	10.89			

2. Of all driveway accidents, 71.62 percent involved a maneuver into or from a commercial establishment.
3. Most of the driveway accidents (85.56 percent) resulted in property damage only; the remainder (14.44 percent) involved personal injury. None of the reported accidents resulted in a fatality.
4. Vehicles turning left into or from driveways were involved in 64.60 percent of all driveway accidents, and 76.00 percent of all driveway accidents resulting in personal injury involved a left turn maneuver.
5. A vehicle entering a driveway was involved in 53.47 percent of the driveway accidents; the remainder involved an exit maneuver.
6. Right-angle collisions made up 60.07 percent of the driveway accidents; rear-end collisions made up 33.09 percent. A majority of the rear-end collisions occurred when the driveway vehicle was struck while waiting to turn into a driveway.
7. Driveway vehicles were struck by through-traffic vehicles in 57.01 percent of the cases, whereas they struck the through-traffic vehicles in 33.34 percent of the cases. The driveway vehicle was not directly involved in the collision in the remainder of the driveway accidents studied.
8. Of all driveway accidents, 72.28 percent occurred during daylight hours when traffic volume is heaviest.
9. Seventy-five percent of the driveway accidents

occurred during periods of nonprecipitation, and 70.05 percent occurred under dry pavement conditions. These results probably reflect the low number of days annually on which weather is inclement.

Significant Data Splits

In this analysis, the data were split into two or more logical categories, and the differences between the groups were compared. Three significant data splits were analyzed in this phase of the study.

The sample consisted of 29 one-way streets and 71 two-way streets. During a 4-year period, two-way streets experienced, on the average, almost 2.75 times the number of driveway accidents per kilometer as did one-way streets (Table 1). However, associated with this statistic is the fact that the one-way streets in this sample had a lower ADT and fewer commercial driveways per kilometer, both of which may explain this difference.

The entire sample of 100 arterial street sections had from one lane to four lanes. Data given in Table 2 show that, as the number of through-traffic lanes increases on the average, the number of driveway accidents per kilometer, the number of commercial driveways per kilometer, and the ADT increase, indicating that different combinations of these variables could have a significant effect on the driveway accident rate.

Although a consistent relationship does not occur, there is a definite trend toward more driveway accidents per kilometer and more commercial driveways per kilometer in higher ADT ranges (Table 3). The ADT ranges into which the sections were categorized were determined by plotting the number of driveway accidents per kilometer against ADT and selecting definite clusters of points as intervals.

Table 1. Driveway accident characteristics on one-way and two-way streets.

Item	One-Way Streets	Two-Way Streets
Number of roadway sections	29	71
Driveway accidents per kilometer	14.816	5.444
Driveway accidents as percentage of total	6.37	16.35
Average ADT, vehicles per day	7582	9905
Commercial driveways per kilometer	10.067	13.248

Note: 1 km = 0.62 mile.

Table 2. Driveway accidents per kilometer, commercial driveways per kilometer, and ADT as a function of the number of through-traffic lanes in both directions.

Number of Lanes	Number of Section Samples	Driveway Accidents per Kilometer	Commercial Driveways per Kilometer	ADT
1	3	0.086	4.711	1 713
2	74	7.464	9.804	7 843
3	5	9.490	17.471	11 648
4	18	31.812	21.373	15 522

Note: 1 km = 0.62 mile.

Driveway Spacing Analysis

The literature recommends longer distances between adjacent driveways and between driveways and adjacent intersection legs, but these conclusions are based on criteria other than the driveway accident rate. To determine the relationships between driveway spacing and the driveway accident rate, scaled maps were reproduced for each of the 92 roadway test sections from the measurements obtained in the earlier field inventories. Two average driveway spacing variables were developed for each roadway section. The average spacing between two adjacent driveways was defined as the sum of the centerline-to-centerline distance between two adjacent driveways divided by the number of times in a section two driveways appeared next to each other. Likewise, the average spacing between a driveway and an adjacent intersection leg was defined as the sum of the centerline-to-centerline distance between a driveway and an adjacent intersection leg divided by the number of times in each section that a driveway appeared adjacent to an intersection leg. Both average spacing variables were developed by considering driveways on both sides of the street.

The technique of analysis was to plot each average spacing variable against the corresponding driveway accident rate of each roadway section. Inasmuch as both plots displayed such a scatter of points that useful, significant information could not be obtained, a least squares technique was used to fit the best possible straight line through the points. The following two regression equations were developed:

$$Y = 7.728 - 0.055\,X_1 \tag{1}$$

$$Y = 11.584 - 0.068\,X_2 \tag{2}$$

where

Y = number of driveway accidents per mile per year,
X_1 = average spacing in feet over a section of roadway between adjacent driveways, and
X_2 = average spacing in feet over a section of roadway between a driveway and an adjacent intersection leg.

(Both equations were developed from an array of data defined in U.S. customary units; therefore, SI units are not given for the variables in these models.)

The correlation between Y and X_1 was -0.166, and the correlation between Y and X_2 was -0.318, indicating that neither of the two driveway spacing variables is related linearly to the driveway accident rate. However, the negative sign preceding the coefficients of the independent variables and the negative sign preceding each of the correlation coefficients suggest a trend toward lower driveway accident rates as driveways are located fur-

Table 3. Driveway accidents per kilometer and commercial driveways per kilometer as a function of ADT.

ADT Range	Number of Sections: Total	One Lane	Two Lanes	Three Lanes	Four Lanes	Driveway Accidents per Kilometer	Commercial Driveways per Kilometer
0 to 5000	22	3	19	0	0	2.451	3.088
5001 to 6800	16	0	15	1	0	4.381	9.461
6801 to 8800	17	0	15	1	1	8.347	10.505
8801 to 10 200	7	0	7	0	0	7.236	8.370
10 201 to 11 900	8	0	5	1	2	10.978	11.094
11 901 to 14 600	13	0	6	1	6	20.126	15.357
More than 14 600	17	0	7	1	9	30.347	26.467

Note: 1 km = 0.62 mile.

ther from other driveways or intersection legs. An increase in either spacing variable implies a decrease in the number of driveways on a section of roadway. This would surely contribute to a decrease in the driveway accident rate.

Relationship Among Driveway Accidents, Roadway Characteristics, and Traffic Volume Characteristics

Analysis Technique

One method for establishing which factors have the greatest effect on the driveway accident rate and their relative order of importance is stepwise linear regression analysis. This technique involves defining a dependent variable, the number of driveway accidents per mile per year, and the number of independent variables that are suspected to have an influence on the dependent variable. This analysis considered a total of 26 independent variables representing the 24 most important and most logical roadway, environmental, and traffic volume factors. Because stepwise multiple regression analysis works by scanning an array of independent variables and choosing in succession those most closely related to the dependent variable, as many independent variables as possible were provided. The independent and dependent variables, as they were coded for computer analysis, are given in Table 4. Curb parking restrictions are further denoted as follows:

X_{23}	X_{24}	Definition
0	0	No parking on both sides of street
1	0	Parking on one side of street only
0	1	Parking on both sides of street

Curb conditions are further denoted as follows:

X_{25}	X_{26}	Definition
0	0	No curbs on both sides of street
1	0	Curbs on one side of street only
0	1	Curbs on both sides of street

Stepwise multiple regression analysis was used to develop equations for combinations of the study sections. One regression equation was developed for each of the following categories: all 92 study sections, all one-way street sections, all two-way street sections, and all two-lane street sections. Four equations were developed by using the same categories of data with the sections from Indianapolis removed. This was done to test the effect of urban area population on the driveway accident rate; nine of the urban areas had populations between 30 000 and 80 000 whereas the population of Indianapolis was 750 000.

The eight regression equations were developed in a three-step process. In the first step, the data were subjected to stepwise regression analysis. Only linear independent variables that effected a significant increase in the multiple correlation coefficient (r^2) were used in the equation. In the second step, a stepwise multiple linear regression was again used, but the independent variables were all of the significant linear terms from the first step and all possible two-way products of these linear terms. These two-way products represent interactions between two independent variables, and these products proved in every case to be more significant than the sum of their component variables. Once again, only those terms that contributed to the increase in the multiple correlation coefficient were used in the equation. Because a model that contains interaction terms must also contain the main effect terms that make up the interaction and because in some cases one or more of the main effect terms were not significant enough to enter the equation in the second step, the third step was introduced to force these main effect terms into the final equations.

Regression Equations

Eight regression equations relating the driveway accident rate to significant roadway and environmental characteristics were developed. They are given below. Based on data from all 92 study sections,

$$\begin{aligned} Y = {} & -7.067 + 0.300(X_1) + 15.550(X_2) + 2.250(X_6) + 0.636(X_{13}) \\ & + 0.075(X_{16}) + 0.024(X_{19}) + 0.024(X_6)(X_{16}) - 0.372(X_6)(X_{13}) \\ & + 0.280(X_2)(X_{19}) - 0.009(X_1)(X_{19}) - 0.010(X_{13})(X_{16}) \\ & + 0.067(X_1)(X_{13}) - 8.067(X_1)(X_2) + 0.461(X_6)^2 \\ & + 0.928(X_2)(X_{16}) \end{aligned} \tag{3}$$

The definitions of the variables are given in Table 4. Based on data from all 92 study sections except Indianapolis,

$$\begin{aligned} Y = {} & +0.130 - 4.583(X_2) - 0.494(X_6) + 0.764(X_{13}) + 0.178(X_{16}) \\ & - 0.130(X_{20}) + 0.079(X_2)(X_{16}) - 0.009(X_{13})(X_{16}) \\ & + 0.082(X_6)(X_{20}) + 320.927(X_2)^2 - 0.448(X_6)(X_{13}) \end{aligned} \tag{4}$$

Based on data from all two-lane study sections,

$$\begin{aligned} Y = {} & +0.170 + 0.010(X_1) + 20.034(X_2) + 0.014(X_{13}) + 0.111(X_{16}) \\ & + 1.413(X_2)(X_{16}) - 0.011(X_{13})(X_{16}) - 0.030(X_1)(X_{16}) \end{aligned} \tag{5}$$

Based on data from all two-lane study sections except Indianapolis,

$$\begin{aligned} Y = {} & -2.211 + 69.795(X_2) + 0.191(X_{13}) + 0.021(X_{14}) + 0.026(X_{16}) \\ & + 1.609(X_2)(X_{16}) - 0.009(X_{13})(X_{16}) + 0.003(X_{14})(X_{16}) \\ & - 3.978(X_2)(X_{13}) \end{aligned} \tag{6}$$

Based on data from all one-way street study sections,

$$\begin{aligned} Y = {} & -1.592 + 8.996(X_2) + 0.179(X_{18}) - 0.006(X_{19}) + 0.970(X_{24}) \\ & + 1.096(X_2)(X_{19}) - 32.035(X_2)(X_{24}) \end{aligned} \tag{7}$$

Based on data from all one-way street study sections except Indianapolis,

$$\begin{aligned} Y = {} & -2.333 + 25.728(X_2) - 0.428(X_7) + 0.378(X_{13}) + 0.031(X_{19}) \\ & + 1.020(X_2)(X_{19}) - 0.032(X_{13})^2 - 0.028(X_7)(X_{19}) \end{aligned} \tag{8}$$

Based on data from all two-way street study sections,

$$\begin{aligned} Y = {} & +21.425 + 0.041(X_1) - 11.070(X_6) + 0.216(X_9) - 0.378(X_{13}) \\ & + 0.043(X_{16}) - 0.041(X_{17}) - 0.053(X_{21}) + 0.060(X_6)(X_{16}) \\ & - 0.001(X_{13})(X_{21}) - 0.015(X_{16})(X_{17}) - 1.379(X_6)(X_9) \\ & - 0.022(X_1)(X_{16}) + 0.019(X_9)(X_{21}) + 2.475(X_6)^2 \\ & + 0.119(X_9)(X_{13}) + 0.029(X_9)(X_{16}) \end{aligned} \tag{9}$$

Based on data from all two-way street study sections except Indianapolis,

$$\begin{aligned} Y = {} & +0.098 + 23.967(X_2) + 1.513(X_6) + 0.225(X_{13}) + 0.167(X_{16}) \\ & - 0.004(X_{21}) + 0.995(X_2)(X_{16}) - 0.016(X_{13})(X_{16}) \\ & + 0.014(X_6)(X_{16}) - 0.010(X_{13})(X_{21}) \end{aligned} \tag{10}$$

Again, these equations were developed from a large array of data, most of which was defined and coded for computer analysis in U.S. customary units. The statistical complexity of the equations makes it difficult to merely apply the conversion factors directly to the coefficients of the appropriate terms to devise equations for the number of driveway accidents per kilometer. However, an increase or decrease in a certain property per mile implies an increase or decrease in that same property per kilometer. This accounts for the use of metric units throughout this paper in spite of the fact that the results were originally obtained in U.S. customary units.

Evaluating the Regression Equations

The most obvious feature of the eight regression equations is their relatively high multiple correlation coefficients, which are given below.

Equation	r^2	Equation	r^2
3	0.85	7	0.86
4	0.86	8	0.87
5	0.71	9	0.84
6	0.78	10	0.82

Table 4. List of variables.

Index	Description
Y	Driveway accidents per mile per year
X_1	1970 urban area population in hundred thousands
X_2	1969 average daily traffic volume in hundred thousands
X_3	Street type; $X_3 = 0$ for one-way streets; $X_3 = 1$ for two-way streets
X_4	Roadway section speed limit (mph)
X_5	Curb-to-curb street width (ft)
X_6	Number of through-traffic lanes
X_7	Lane markings; $X_7 = 0$ for no lane markings; $X_7 = 1$ for lane markings visible
X_8	Number of stop signs and red flashing traffic signals per mile
X_9	Number of traffic signals per mile
X_{10}	Number of yield signs and yellow flashing traffic signals per mile
X_{11}	Number of 3-way intersections per mile
X_{12}	Number of 4-way intersections per mile
X_{13}	Number of total intersections per mile
X_{14}	Number of alleys per mile
X_{15}	Number of residential driveways per mile
X_{16}	Number of commercial driveways per mile
X_{17}	Number of industrial driveways per mile
X_{18}	Number of other driveways per mile
X_{19}	Number of total driveways per mile
X_{20}	Number of friction points per mile
X_{21}	Average spacing between adjacent driveways (ft)
X_{22}	Average spacing between driveways and adjacent intersection legs (ft)
X_{23}, X_{24}	Curb parking restrictions
X_{25}, X_{26}	Curb condition

Introducing cross products into the models added considerably to the numerical value of r^2.

Without a doubt, the variable having the most significant effect effect on the driveway accident rate was the number of commercial driveways per kilometer. Only in the one-way street analysis did this variable prove to be insignificant. This is probably due to the low number of one-way streets and the lack of substantial commercial development fronting those one-way street sections used in this analysis. Further computations using the models indicated that each commercial driveway to an arterial street adds between 0.1 and 0.5 driveway accident/mile/year (0.6 and 3.1 accidents/km), depending primarily on the ADT and the number of traffic lanes on the arterial. Other independent variables that seem to have an important effect on the driveway accident rate are the number of through-traffic lanes, the arterial highway ADT, and the number of total intersections per kilometer. Computations revealing the mathematical sign preceding each of these significant variables indicated that the driveway accident rate increases as the number of commercial driveways per kilometer increases, as the urban arterial ADT increases, as the number of traffic lanes increases, and as the number of total intersections per kilometer decreases. Only minor deviations attributable to variable interactions were evident in the analysis. These results are not only inherent from the models, but exactly as one would expect in a real situation. It is significant to note that the number of residential driveways per kilometer is related in no way to the driveway accident rate.

The effect of urban area population was significant. This variable entered the regression equation as a moderately significant predictor of the dependent variable when the Indianapolis sections were included in the analysis, but it had no significance whatsoever when these sections were omitted. In addition, in most cases, the arterial highway ADT was more significant as an independent variable when the Indianapolis sections were not included in the analysis.

One of the major findings of this study was that the product of two independent variables was superior to the sum of the same two variables as a predictor of the dependent variable. These products represent interactions between variables, and their possible use in this analysis was first brought to light during the discussion on driveway accident characteristics. The two most significant interactions in this study were those between the number of through-traffic lanes and the number of commercial driveways per kilometer and between the ADT and the

Table 5. Range of significant variables.

Sample	Variable	Index	Maximum	Minimum	Range
92 sections	Driveway accidents per kilometer per year	Y	17.0	0	17.0
	Urban area population	100 000(X_1)	744 624	31 403	713 221
	ADT	100 000(X_2)	31 034	1153	29 881
	Number of traffic lanes	X_6	4	1	3
	Lane markings	X_7	1	0	1
	Traffic signals per kilometer	X_9	7.3	0	7.3
	Total intersections per kilometer	X_{13}	14.7	1.7	13.0
	Alleys per kilometer	X_{14}	21.9	0	21.9
	Commercial driveways per kilometer	X_{16}	45.5	0	45.5
	Industrial driveways per kilometer	X_{17}	16.7	0	16.7
	Other driveways per kilometer	X_{18}	13.6	0	13.6
	Total driveways per kilometer	X_{19}	74.1	16.1	58.0
	Friction points per kilometer	X_{20}	81.0	22.0	59
	Driveway-driveway spacing (meters)	X_{21}	40.6	7.7	32.9
	Parking	X_{24}	1	0	1
64 two-way sections	Driveway accidents per kilometer per year	Y	17.0	0	17.0
	Urban area population	100 000(X_1)	744 624	31 403	713 221
	Number of traffic lanes	X_6	4	2	2
	Traffic signals per kilometer	X_9	5	0	5
	Total intersections per kilometer	X_{13}	12.9	1.7	11.2
	Commercial driveways per kilometer	X_{16}	45.5	0	45.5
	Industrial driveways per kilometer	X_{17}	16.7	0	16.7
	Driveway-driveway spacing (meters)	X_{21}	40.1	8.7	31.4

Note: 1 km = 0.62 mile; 1 m = 3.28 ft.

number of commercial driveways per kilometer. In the first case, more commercial driveways per kilometer are generally found on highways with more traffic lanes. As both of these variables increase in numerical value, so does the driveway accident rate, on the average. The same analogy can be found in the second case. That is, the two variables seem to increase or decrease in value at approximately the same rate as the dependent variable; thus, the interaction is represented by the product of the two terms.

At first glance, any one of the eight equations may seem difficult to use. However, an engineer can quickly determine the driveway accident rate of a particular stretch of roadway by knowing a maximum of only seven roadway factors and applying them in proper sequence in the appropriate regression equation. Each equation should produce reasonably reliable results, as long as the data entered into the equation are within the range used to develop each. The range of each variable, however, varies in each of the eight equations because of the different source of data from which each was developed. For purposes of comparison and general information, the ranges of significant variables associated with equation 3, which was developed from the data of all 92 roadway sections, and with equation 9, which was developed from the data of all 64 two-way street sections, are given in Table 5. Table 5 also indicates the range of all other variables that were significant in at least one of the other equations. In most cases, as is evident by comparing the data, the range of a certain variable in a given equation will be less than that given in Table 5. These equations can be used not only to provide a reasonable estimate of the driveway accident rate on a particular segment of undivided arterial highway, but also to indicate how much of a change is required in one or more roadway characteristics to effect a desired change in the driveway accident rate.

Testing the Models

The eight models were tested by using each to predict the driveway accident rate that would occur on a particular study section in 1971 and by comparing those results with the actual 1971 driveway accident rate. These two figures were compiled for each study section, and the individual differences between the actual and the predicted driveway accident rates were used to develop a multiple correlation coefficient.

When these eight multiple correlation coefficients were compared to those associated with each respective model, differences were obvious and excessive. In addition, the differences between the actual and predicted driveway accident rates indicated extreme variance. For example, the regression equation developed on the basis of data from all 92 study sections explained 85 percent of the variation of the averaged 1968 to 1970 driveway accident rate, but this same equation explained only 53 percent of the variation in the 1971 driveway accident rate. Likewise, the accompanying residuals ranged in value from 19.8 to -13.4 for a range of 33.2.

The results are not an indication of unreliability in the predictive capacities of the models. Rather, they emphasize the importance of the major controls incorporated throughout this study. In all cases, models developed on the basis of the annual average of a 3-year accident history (1968 to 1970) were used to predict a 1-year accident history. It is possible, in some cases, that the 1971 driveway accident rate for a given section does not agree statistically with its corresponding 1968 to 1970 averaged driveway accident rate. In fact, preliminary computations indicated a higher value of r^2 and a smaller range of residuals when sections having obvious discrepancies between the two driveway accident rates were omitted from this phase of the analysis. It is obvious from the study that the models will predict a 3-year annual average driveway accident rate and not a driveway accident rate based on a 1-year accident history.

CONCLUSIONS

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

1. Driveway accidents represent a significant percentage of the total traffic accident experience on urban arterial highways, and steps taken to effect their decrease would improve overall highway safety.
2. Public officials should consider measures such as barrier medians, traffic signals, left turn lanes, and left turn prohibitions at certain driveways as a means to effect a reduction in driveway accidents and in personal injuries resulting from such accidents.
3. The driveway accident rate tends to decrease when the average spacing over a section of arterial highway between adjacent driveways and between a driveway and an adjacent intersection leg increases.
4. Certain roadway and environmental factors and traffic volume characteristics can be used to predict the annual number of driveway accidents per mile significantly better than they can predict the number of driveway accidents per 100 million vehicle-miles.
5. The interaction, or product, of two variables proved to be more significant, in every case, than the sum of the same two variables in predicting the number of driveway accidents per mile per year.
6. Driveway accident rates based on the annual average of a 3-year accident history produce better results in regression analysis when it can be shown that the 3 separate years of accidents used to derive the rates originated from the same population.
7. The number of driveway accidents per kilometer per year will decrease when (a) the number of commercial driveways per kilometer is reduced, (b) the number of through-traffic lanes is reduced, (c) the number of total intersections per kilometer is increased, (d) the number of total driveways per kilometer is reduced, or (e) the arterial highway ADT is reduced. Other factors were shown to have a less pronounced effect on the driveway accident rate.
8. Urban area population can be used as a significant predictor of the driveway accident rate when the study samples are derived from urban centers whose population differences are significantly large. However, the effectiveness of this variable as a predictor decreases rapidly as this difference becomes less pronounced. This may be due to the fact that motorists from larger cities are more accustomed to traveling on urban arterial highways.
9. Mathematical models describing the driveway accident rate on one-way streets, two-way streets, and two-lane streets are not statistically or analytically different from the model describing all study sections.
10. These mathematical models can be used not only to predict a future driveway accident rate but also to present facts defending decisions on controlling the number of access points for the public well-being. Used within the constraints from which they were developed, the models can be valuable tools to all public officials concerned with the number of driveway accidents in their cities.

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