# Effect of Traffic and Roadway Features on Utility Pole Accidents

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ABSTRACT

The purpose of this study was to determine the effect of various traffic and roadway variables on the frequency and severity of utility pole accidents. Detailed roadway and accident data were collected from each of 1,534 sections consisting of more than 2,500 miles (4000 km) of urban and rural roadway in four states. The data were analyzed by using several statistical techniques, including correlation analysis, analysis of variance and covariance, and contingency table analysis. Lateral pole offset, traffic volume, and pole density were of primary importance in explaining the variation in the frequency of utility pole accidents. In terms of accident severity, wood poles were associated with significantly higher severities than metal poles for sections with pole offsets within 10 ft (3 m). This was due to the frangible bases on most metal poles in the sample. Accident severity increased significantly with increasing roadway curvature for some speed limit categories. Linear and nonlinear regression analyses were used to develop a model to predict utility pole accident experience as a function of roadway and utility pole characteristics. The model was validated and indicated satisfactory predictive capabilities. A nomograph was developed based on the model to allow for simple graphical determination of expected utility pole accident experience for various roadway conditions.

Detailed studies conducted to examine the effects of roadway variables on utility pole accidents are important for use in developing countermeasures for utility pole accidents. In the past most studies related to utility pole accidents have involved either a general summary of accident statistics or an in-depth analysis of individual accidents to determine factors that affect the severity of utility pole accidents. Although these studies are useful for certain purposes, they have not allowed for the quantification of true relationships between the frequency of utility pole accidents and roadway features. Thus there is currently a need to determine how utility pole accidents are affected by pole offset distance and pole density. Such information can then be used to estimate the effects of various utility pole treatments (i.e., relocating poles or reducing pole density) on accidents.

The purpose of this study was to determine the effect of various traffic and roadway variables on both the frequency and severity of utility pole accidents. The study involved the collection and analysis of roadway, roadside, and utility pole accident data for each of 1,534 sections totaling more than 2,500 miles (4000 km) of roads in four states. The collection of data involved the use of agency files, photologs, police accident records, and some site visits. Statistical analysis techniques were conducted on the data base to quantify which variables have a significant relationship to utility pole accidents.

## BACKGROUND

### Factors Associated with Frequency of Utility Pole Accidents

Several studies have been conducted that have attempted to determine factors that affect the frequency of utility pole and other fixed-object accidents. In 1980 Jones and Baum (1) reviewed more than 8,000 single-vehicle accidents in 20 urban areas and found that the number of poles (pole density or pole spacing) was the most important variable in predicting the probability of utility pole accidents. Lateral pole offset was the next most important variable, followed by road grade, road path, and speed limit.

In 1980 Mak and Mason (2) completed a detailed study of accidents involving utility poles, sign poles, and light poles in seven geographic areas in the United States. Pole accidents were found to be primarily an urban problem, with 85 percent of the pole accidents occurring in urban areas. The overall rate in terms of pole accidents per 100 million vehicle miles was 16 (9.9 accidents per hundred million vehicle kilometers). Mak and Mason also found that the frequency of pole accidents was related to pole density, pole offset, and horizontal and vertical alignment.

Fox et al. (3) developed an accident predictive model to identify the risk of nonintersection and intersection pole accidents. The nine variables used in the nonintersection model included average daily traffic (ADT), lateral pole offset, pavement skid resistance, roadway width, horizontal curvature, distance between the poles and start of the curve, pavement deficiencies, superelevation at the curve, and pole location.

Wright and Mak (4) conducted a study in 1976 to determine relationships between single-vehicle, fixed-object accidents and roadway and other variables on urban two-lane roads in Georgia. Accident rates were found to be highly related to volume, horizontal alignment, and the number of intersections per mile. Wright and Robertson (5) conducted a study in 1979 of 300 fatal fixed-object accidents on rural Georgia roads to set priorities for removal or modification of roadside hazards. The factors found to be associated with roadside hazards were curvature (greater than 6 degrees) and downhill gradient (-2 percent or less) before or at the curves. A great majority of fatal accidents also occurred on the outside of the curve.

A study by Perchonok et al. (6) in 1978 involved an investigation of relationships between single-vehicle accidents and roadway and roadside features. Data were collected for more than 9,000 single-vehicle accidents on rural roads in six states. Horizontal alignment was a major factor related to accidents, with more than 40 percent of the accidents occurring at curves. Left curves and downgrades were overrepresented in accidents, and accidents were also overrepresented at the beginning of curves.

In a 1978 study Cleveland and Kitamura (7) developed a macroscopic model of roadside accidents on two-lane rural roads in Michigan. The study involved collecting and analyzing data for 270 two-mile (3.2-km) roadway sections with a variety of geometric and traffic conditions. Models were developed for different volume groups. The most important variables for accident prediction were restriction on passing sight distance, roadside obstacle frequency, and length of road with roadside obstacles within various distances from the road.

### Factors Associated with Severity of Utility Pole Accidents

Several researchers have investigated the effect of traffic and roadway variables on the severity of utility pole accidents. Jones and Baum (1) found that 49.7 percent of all utility pole accidents resulted in personal injury. Impact speeds and pole circumference were observed to be related to the severity of utility pole accidents, but the spacing and offset of utility poles were not found to affect the severity of utility pole accidents.

Mak and Mason (2) reported in 1980 that there is a 50 percent chance that at least one vehicle occupant in a utility pole accident will be injured. Of the 1,000 utility pole accidents considered in the study, 518 (51.8 percent) involved one or more injuries, and 16 (1.6 percent) resulted in one or more fatalities. Vehicle impact speed was a major factor in accident severity, whereas other factors found to be related to the severity of utility pole accidents included pole type, presence of breakaway poles, vehicle characteristics (weight, size, and so forth), and impact configuration (location and direction of impact).

In a 1981 study of single-vehicle accidents in Texas, Griffin (8) found that 44.7 percent of utility pole accidents involved a personal injury. Further, about 33.5 percent of utility pole accidents involved moderate injury or greater (B type injury) and 5.8 percent involved a serious injury (A type injury) or fatality. In their study of clear recovery zones, Graham and Harwood (9) found no relationship between clear recovery zone policy (i.e., 6:1 clear zone, 4:1 clear zone, no clear zone) and the severity of fixed-object accidents.

Fox et al. (3) found that accidents on curves were slightly more severe than those on straight sections because of the increased number of side impacts occurring on curves. The severity of pole accidents was higher at nonintersections than at intersections. This was probably caused by lower speeds at intersections.

## SITE SELECTION AND DATA COLLECTION

### Determination of Sampling Requirements

To fulfill the research objectives, a sample of roadway, traffic, utility pole, and accident data was needed. A sampling plan was formulated to obtain data for a large number of individual highway sections to allow for statistical testing of relationships between utility pole accidents and various roadway-related variables. Because a representative sample of data sites was needed (i.e., locations with zero accidents as well as accident sites), a section length of 0.4 mile (0.6 km) or greater was chosen as the base for the analysis.

A basic requirement for sampling was that only sections with utility poles were selected, because sections with no utility poles served no useful purpose for the analysis. Although the treatment of light poles (i.e., metal luminaire poles) was not a primary concern in this study, data for many sections with luminaires were collected (mostly in urban areas) because accident frequencies on roadways with light poles should be comparable to those with utility poles. This hypothesis, however, does not hold true for accident severity due to different pole types.

Sampling was structured to ensure adequate data samples in urban and rural areas over a wide range of traffic volumes (ADT of 1,000 to 60,000) and for a variety of terrain conditions. For urban and suburban areas, curbed and uncurbed roadway classes were also defined for data-collection purposes.

Sample size calculations were performed to determine the minimum number of miles of roadway to be sampled in each roadway class. Assuming that utility pole accidents follow a Poisson distribution, sample size requirements for each roadway class were computed based on the expected utility pole accidents within each class. A minimum of 1,700 miles (2700 km) of highway was required for analysis purposes, whereas 2,519.3 miles (4053.6 km) of data were actually collected, as discussed later.

### Selection of Data Variables

Based on the literature review, a list was made of highway and traffic variables with proven or logical relationships to utility pole accidents. Based on this list and consideration of other potentially useful variables, the data variables to be collected for each highway section were selected. The selected variables and other necessary information are given in Table 1 along with the source of data (i.e., from highway agency files, from photologs, or from state police records).

The procedure used for collecting lateral distance and obstacle information was conducted on a pole-by-pole basis. Each utility pole was designated as either clear, partially obstructed, or totally obstructed, depending on the number and position of obstacles within the encroachment envelope of that pole. This encroachment envelope is the triangular area formed between the departure angles of 3 degrees and 90 degrees, which was based on data of encroachment angle and pole accidents as found by Mak and Mason (2). Only obstacles falling within this triangular area were counted, as illustrated in Figure 1. The obstacles were subsequently classified as point obstacles (trees, signposts, mailboxes, and so forth) or linear obstacles (guardrail, walls, and so forth). This obstacle information was used to determine the number of obstructed, partially obstructed, and unobstructed poles per section.

One of the most important variables collected for each roadway section was the lateral offset distance of each pole from the edge of the roadway. The offset distance of each pole was measured to the nearest foot, and only those section with pole offsets within 30 ft (10 m) in rural areas and 20 ft (6 m) in urban areas were included in the data base. The number and types of utility poles in each roadway section were also recorded. In addition to highway and traffic data, the utility pole accident variables for each section were also recorded (Table 1).

### Selection of Data-Collection Sites

One of the most important considerations in selecting sites was the accuracy and completeness of acci-

TABLE 1 Data Source for Each Variable

| Variables Collected | Highway Agency Files | Photologs | State Police |
|---|---|---|---|
| **Roadway Variables** | | | |
| State | S | P | - |
| County | S | P | - |
| Route Number or Name | S | P | - |
| Milepoints | - | P | - |
| Section Length | - | P | - |
| Area Type | S | P | - |
| Number of Lanes | S | P | - |
| Roadway Operation | S | P | - |
| Terrain | - | P | - |
| Curvature | - | P | - |
| Traffic Volume (ADT) | P | - | - |
| Speed Limit | S | P | - |
| Pavement Type | - | P | - |
| Shoulder Type | S | P | - |
| Shoulder Width | S | P | - |
| Side Slope | - | P | - |
| Median Type | S | P | - |
| Number of Signalized Intersections | - | P | - |
| Presence of lighting | - | P | - |
| **Utility Pole Variables** | | | |
| Pole Location | - | P | - |
| Pole Lateral Distance | - | P | - |
| Pole Spacing | - | P | - |
| Pole Type | - | P | - |
| Pole Diameter | - | P | - |
| Pole Obstructions | - | P | - |
| **Accident Variables** | | | |
| Roadway section | - | - | P |
| Milepoint | - | - | P |
| Accident Severity | - | - | P |
| Date of Accident | - | - | P |
| Time of Accident | - | - | P |
| Weather Conditions | - | - | P |
| Road Surface Conditions | - | - | P |
| Lighting Conditions | - | - | P |
| Roadway Alignment | - | - | P |
| Driver Intent | - | - | P |
| **Other Variables** | | | |
| Construction | P | - | - |

P = Primary source of data
S = Secondary source of data

dent and other data variables. Data were collected from state-maintained roadways only because state highway agencies commonly maintain computerized accident and roadway data files in both urban and rural areas. The four states selected that best met the data-collection requirements were Michigan, Colorado, Washington, and North Carolina.

Data-collection sites were selected within each state by first obtaining a list of homogeneous highway sections where utility poles exist within the highway right-of-way, with consideration given to fulfilling the data requirements for the various classification schemes. Each site was at least 0.4 mile (0.6 km) long, and sites were omitted that had major construction (i.e., roadway widening or pole relocation) in recent years. Sites were generally picked without on-street parking, because a continuous line of parked cars acts as a barrier between the traffic lanes and fixed objects.

## Collection of Data

Locational, roadway, and utility pole variables were extracted primarily from photologs. The photologs used in this study were 35-mm photographs of the roadway environment taken from a moving vehicle in equal distance increments of 100 frames per mile. Sections selected for data collection were viewed by trained technicians, who recorded the locational, roadway, and utility pole variables selected for analysis. Lateral and longitudinal distance information (shoulder widths and pole offset distances) were obtained by using a calibrated grid placed over the photolog viewing screen.

In addition to photologs, some roadway data were collected from agency files, maps, and other documents. Computerized accident data summaries were obtained from state police or from the state highway agencies. Only accidents involving utility or luminaire poles were obtained for use in the study. All utility pole accidents from the various state computer listings were recoded in a common format for analysis purposes.

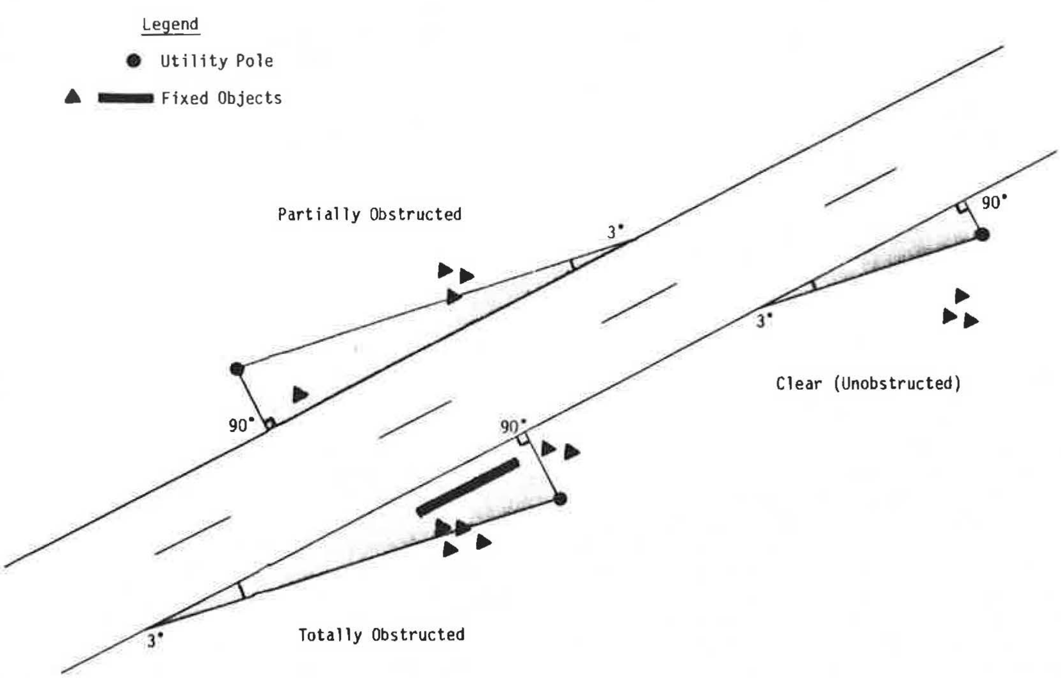



FIGURE 1 Illustration of clear, partially obstructed, and totally obstructed poles based on positioning of obstacles within the encroachment envelope.

The accident data base included 5 years of data from Colorado (1975 through 1980), 6 years in North Carolina (January 1, 1975 through Dcocmber 31, 1980 for rural areas and July 1, 1975 through June 31, 1981 for urban areas) and Washington (1975 through 1980), and up to 10 years in Michigan (1971 through 1980).

### Data Checking and Editing

The roadway and accident data were collected and transferred to coding forms for keypunching. Before keypunching, all coded forms were reviewed to ensure they were properly completed. The data were then keypunched, verified, and read into a computerized file. A series of checks was made on the data base to identify possible errors or illogically coded data. Logic checks were then made by using a computer program, and field inspections were made to verify certain information.

## DATA ANALYSIS

The first step in the analysis was to determine the relationship between variables that significantly affect the frequency or severity of utility pole accidents. These relationships were then used to develop models to estimate the accident frequency under given site conditions.

To accomplish this objective, the analysis approach was formulated to answer the following questions.

1. What are the dimensions of the utility pole accident problem? How many utility pole accidents are reported annually on urban and rural highways? What is the severity of these accidents?
2. What factors or combination of factors significantly affect the frequency of utility pole accidents? What is the relationship between various roadway characteristics and utility-pole-related accidents? Can these relationships be used to estimate the effectiveness of utility pole countermeasures?
3. What factors or combination of factors significantly affect the severity of utility pole countermeasures? Do roadway and traffic characteristics affect the percentage of injury and fatal accidents involving utility poles? What are the relationships between accident severity and utility pole accident countermeasures?

The analysis approach used to address these major issues is discussed in the following sections.

### General Description of Data Base

The data base consisted of 1,534 highway sections representing 2,519.3 miles (4053.6 km) of roadway, or an average of 1.64 miles (2.64 km) per site. Section lengths ranged from 0.4 to 14.7 miles (0.6 to 23.6 km) long. The sample consisted of 1,076.6 miles (1732.2 km) from Michigan, 636.5 miles (1024.1 km) from Washington, 586.8 miles (944.2 km) from North Carolina, and 219.4 miles (353.0 km) from Colorado. A majority of the data were collected for rural highways (64.7 percent), whereas urban areas comprised 12.5 percent of the data base and urban fringe areas comprised the remaining 22.8 percent of the roadway miles. Two-way, two-lane roads comprised 1,847.1 miles (2972.0 km) of the data collected, whereas multilane undivided and multilane divided roadway types accounted for 433.1 miles (696.9 km) and 219.9 miles (315.8 km) of the data base, respectively. In addition, 19.2 miles (30.9 km) of data were collected on one-way streets.

### General Description of Utility Pole Accident Problem

Data were analyzed for a total of 9,583 utility pole accidents on the 2,519.3 miles (4053.6 km) of roadway. Accident data for time periods of 2 to 10 years (with an average of 8.13 years) were used, depending on the amount of data available from each state.

The utility pole accident frequency ranged from 6.4 accidents per mile per year (acc/mi/yr) [4.0 accidents per kilometer per year (acc/km/yr)] to 0 acc/mi/yr, with the overall average accident experience of 0.565 acc/mi/yr (0.351 acc/km/yr) and a standard deviation of 0.940. A total of 419 sections representing 525.8 miles (846.0 km) of roadway (20.9 percent) experienced no utility pole accidents during the analysis period.

The overall accident rate was 16.61 utility pole accidents per hundred million vehicle miles (acc/HMVM) [10.32 accidents per hundred million vehicle kilometers (acc/HMVKm)]. This value compares closely with the 16 utility pole acc/HMVM (9.94 acc/HMVKm) found by Mak and Mason in their 1980 study (2). The rate of accidents per billion vehicle-pole interactions was 4.11, which is slightly higher than the rate of 3.4 found by Mak and Mason.

Utility pole accident characteristics summarized by state and area type are given in Tables 2 and 3. Frequencies of utility pole accidents were highest in urban areas, with 1.87 acc/mi/yr (1.16 acc/km/yr) compared with 0.72 acc/mi/yr (0.47 acc/km/yr) in urban fringe areas and 0.18 acc/mi/yr (0.11 acc/km/yr) in rural areas. The accident rate was 26.95 acc/HMVM (16.75 acc/HMVKm) in urban areas, compared with 19.53 acc/HMVM (12.13 acc/HMVKm) in urban fringe areas and 12.76 acc/HMVM (7.87 acc/HMVKm) in rural areas. In terms of accidents per billion vehicle-pole interactions (acc/BVPI), urban and rural areas were about the same (5.2 and 5.0, respectively), with the urban fringe areas slightly lower (4.1 acc/BVPI).

An examination of the severity of utility pole accidents indicated that 52.7 percent of the utility pole accidents were property damage, 46.3 percent were injury accidents, and 1.0 percent were fatal accidents. The percentage of accident severities was virtually identical for urban and rural areas. These values compare closely with the results of previous studies.

### Correlation Analysis

Correlation analysis was conducted to determine if a relationship exists between the independent variables and the dependent variables, and to identify the existence of relationships between the independent variables. Determining the association between independent variables is useful in avoiding problems with collinearity.

The dependent variables in this analysis included (a) utility pole accident frequency (acc/mi/yr), (b) utility pole accident rate (acc/HMVM), and (c) utility pole accident rate (acc/BVPI). The independent variables included ADT, pole density, total pole density (including obstructed and unobstructed poles), density of clear and partially obstructed poles, and pole offset. The pole offset used was the average (i.e., mean lateral distances of poles from the roadway within a give section). Pole density corresponded to the number of clear (unobstructed) poles.

TABLE 2 Summary of Utility Pole Accidents by State

| State | Sections | Miles | Utility Pole Accident Frequency (Acc/Mi/Yr) | Utility Pole Accident Rate (Acc/HMVM) | Utility Pole Accident Rate (Acc/BVPI) |
|---|---|---|---|---|---|
| Colorado | 80 | 219.4 | 1.01 | 16.5 | 4.94 |
| Michigan | 878 | 1076.6 | 0.60 | 15.4 | 4.16 |
| N. Carolina | 379 | 586.8 | 0.40 | 13.9 | 4.10 |
| Washington | 197 | 636.5 | 0.56 | 27.3 | 9.67 |
| Total | 1534 | 2519.3 | 0.57 | 16.6 | 4.89 |

Note: 1 mile = 1.6 km
1 accident/mile/year = 0.6 accidents/km/year
1 accident/HMVM = 0.6 accidents/HMVkm

TABLE 3 Summary of Utility Pole Accidents by Area Type

| Area Type | Sections | Miles | Utility Pole Accident Frequency (Acc/Mi/Yr) | Utility Pole Accident Rate (Acc/HMVM) | Utility Pole Accident Rate (Acc/BVPI) |
|---|---|---|---|---|---|
| Urban | 216 | 316.2 | 1.87 | 26.95 | 5.19 |
| Urban Fringe | 421 | 573.2 | 0.72 | 19.53 | 4.44 |
| Rural | 897 | 1629.9 | 0.18 | 12.76 | 5.04 |
| Total | 1534 | 2519.3 | 0.57 | 16.61 | 4.89 |

Note: 1 mile = 1.6 km
1 accident/mile/year = 0.6 accidents/km/year
1 accident/HMVM = 0.6 accidents/HMVkm

A correlation matrix was generated for all variable combinations, where the Pearson correlation coefficient (r) was calculated for each pair of variables. The independent variables most highly correlated with the frequency of utility pole accidents included ADT ($r = 0.606$), pole offset ($r = -0.592$), and pole density ($r = 0.520$). These correlation coefficients were significant at the $\alpha = 0.01$ level. Because volume is highly correlated to accident frequency, considerably lower correlation coefficients were found for the rate-based dependent variables. This was an expected result based on the findings reported in the literature.

The level of association between important independent variables was low ($r^2$ between 0.13 and 0.22). Thus these Pearson correlation coefficients were considered to be low enough to allow their use together in a predictive model of utility pole accidents.

Kendall tau correlation analysis was used to measure the association between the discrete, ordinal independent variables. For example, the highest correlation (tau value of 0.727) was between area type and speed limit. This is because speed limits in rural areas were nearly all 50 or 55 mph (80 or 88 km/h), whereas speed limits in urban areas were generally less than 45 mph (72 km/h). This information was used to delete intercorrelated variables and select the best variables for use in the predictive models.

## BRANCHING ANALYSIS

The branching analysis was conducted to identify specific relationships between the roadway variables and utility pole accidents. Although the correlation analysis indicated that several of the roadway variables are individually related to the accident variables, correlation analysis does not identify combinations of roadway variables related to utility pole accidents. The branching analysis program selects the roadway variables (independent variables) that account for the largest amount of explained variance in the utility pole accident variable (dependent variable). A separate branching analysis was conducted for utility pole accident frequency (acc/mi/yr), utility pole accident rate (acc/HMVM), and utility pole accident rate (acc/BVPI).

For each dependent variable, the same three independent variables identified in the correlation analysis contributed significantly to the percentage of explained variance. However, the percentage of explained variance was considerably different for each dependent variable, as follows:

| Dependent Variable | Percentage of Variance Explained |
|---|---|
| Utility pole accident frequency (acc/mi/yr) | 61.2 |
| Utility pole accident rate (acc/HMVM) | 36.9 |
| Utility pole accident rate (acc/BVPI) | 18.5 |

Based on the percentage of explained variance for the three dependent variables, the accident frequency variable (acc/mi/yr) is preferable for predictive purposes than the accident rate variables.

The specific branching diagram for utility pole accidents and roadway characteristics is shown in Figure 2. Pole offset is the single factor that explains the largest amount of variance in utility

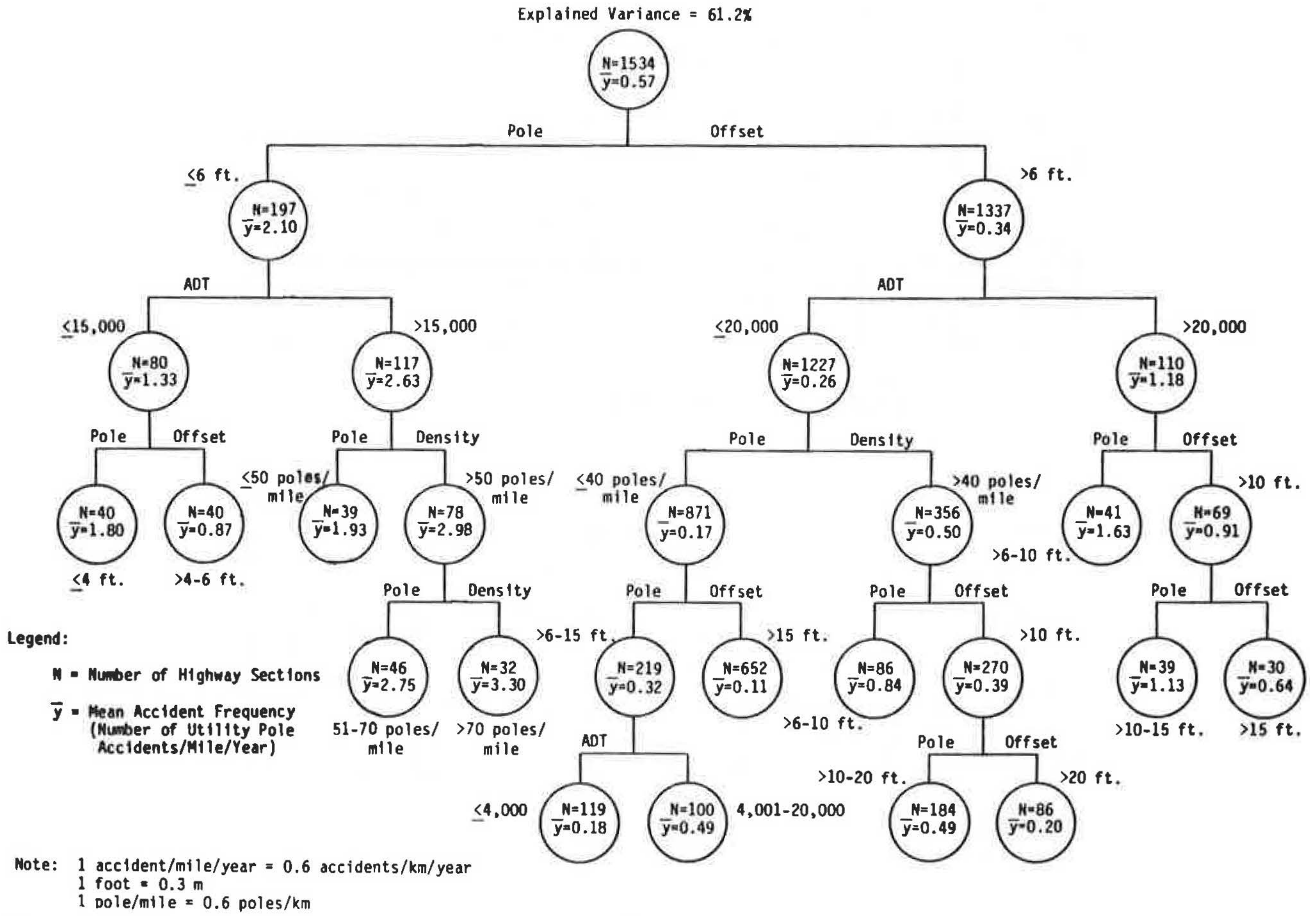



FIGURE 2 Branching diagram for the number of utility pole accidents per mile per year.

pole accidents per mile per year. In reviewing the terminal cells of the branching diagrams, highway sections with the highest utility pole accident occurrence have a pole density of 70 poles per mile (45 poles/km) or more, an ADT volume greater than 15,000, and an average pole offset of 6 ft (1.8 m) or less. In contrast, sections with the lowest number of utility pole accidents have pole offsets greater than 15 ft (24 m), pole densities of less than 40 poles per mile (25 poles/km), and an ADT volume of 20,000 vehicles or less.

## Analysis of Variance and Covariance

In the branching analyses traffic volume, pole offset, and pole density were found to be of primary importance in explaining the variation in utility pole accident experience. To examine differences in mean utility pole accidents for these variables, a three-way analysis of variance was conducted. The results of the test indicate that the mean number of utility pole accidents per mile per year is significantly different for the various volume, pole density, and pole offset groupings. The three-way interaction among the factors is statistically significant, which suggests that the variables tend to explain some of the same variance in utility pole accidents. A further examination of the cell means led to the following observations:

1. The frequency of utility pole accidents increases significantly with increases in traffic volume ($\alpha$ = 0.001 level of confidence),
2. Utility pole accidents decrease significantly with increasing pole offsets ($\alpha$ = 0.001 level of confidence), and
3. Utility pole accidents increase significantly with increasing pole densities ($\alpha$ = 0.001 level of confidence).

The analysis of variance results indicate that the mean number of utility pole accidents is significantly affected by the average pole offset, traffic volume, and pole density. These variables are also continuous independent variables that can be used as covariates. Because of the interrelationships previously identified among many of the roadway variables, it is not possible to use the analysis of variance to determine if a difference in means is due to the factor being tested or attributable to other variables. However, the analysis of covariance permits controlling for the effects of other factors, and then testing the differences in means between identified groups by using standard analysis of variance procedures.

A series of analysis of covariance tests were conducted by using configurations of two roadway variables as factors (i.e., area type, speed) and the three covariates (pole offset, traffic volume, and pole density). The results of the tests are given in Table 4. Based on this analysis it appears that there are statistically significant differences among the group means for utility pole accidents for six roadway variables, which include state in which the data were collected, roadway classification, shoulder width, horizontal curvature, lighting, and speed limit. This implies that when controlling for

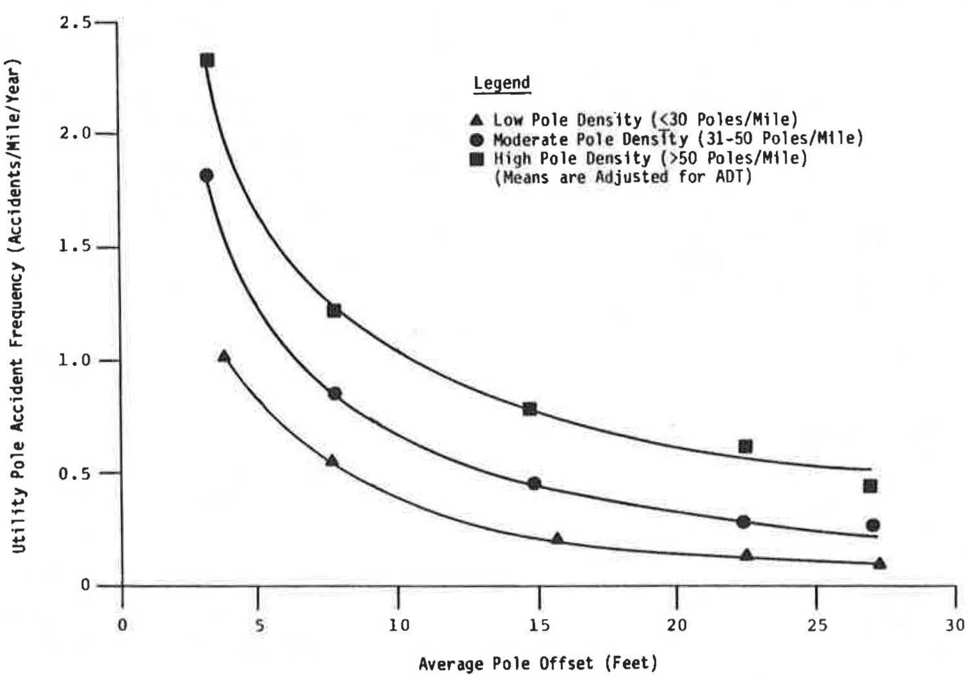
TABLE 4 Analysis of Variance Results for Volume, Pole Offset, and Pole Density

| Source of Variation | Sum of Squares | Degrees of Freedom | Mean Square | F Statistic | Significance of F |
|---|---|---|---|---|---|
| Main Effects | 803.99 | 10 | 80.39 | 239.51 | 0.00 |
| ADT | 121.34 | 4 | 30.33 | 90.37 | 0.00 |
| Pole Offset | 212.66 | 4 | 53.16 | 158.38 | 0.00 |
| Pole Density | 19.60 | 2 | 9.80 | 29.20 | 0.00 |
| 2-Way Interactions | 45.40 | 32 | 1.41 | 4.22 | 0.00 |
| ADT-Offset | 23.30 | 16 | 1.45 | 4.33 | 0.00 |
| ADT-Density | 4.72 | 8 | 0.59 | 1.75 | 0.08 |
| Offset-Density | 5.02 | 8 | 0.62 | 1.87 | 0.06 |
| 3-Way Interactions | 13.93 | 28 | 0.49 | 1.48 | 0.05 |
| ADT-Offset-Density | 13.93 | 28 | 0.49 | 1.48 | 0.05 |
| Explained | 863.33 | 70 | 12.33 | 36.74 | 0.00 |
| Residual | 491.08 | 1463 | 0.33 | | |
| Total | 1354.42 | 1533 | 0.88 | | |

the three covariates and one other factor, these variables have a significant impact on accident experience.

There were no significant differences in the accident means for the following variables: area type, number of lanes, pole type, and side slope. This implies that when controlling for volume, pole offset, and pole density, these variables did not have a significant impact on accident frequency. A significant interaction between factors indicates that both variables tend to explain the same variance in utility pole accidents, and these variables should not be used together in a regression equation.

The accident relationships for pole offset with three levels of pole density and adjusted for traffic volume are shown in Figure 3. The sensitivity of utility pole accidents can be seen as a function of both pole offset and pole density. The isolated effect of ADT is illustrated in Figure 4. The results of these analyses were used to develop accident reduction factors along with the regression equations.




Note: 1 foot = 0.3 m
1 pole/mile = 0.6 poles/km
1 accident/mile/year = 0.6 accidents/km/year

FIGURE 3 Relationship between frequency of utility pole accidents and pole offset for three levels of pole density.

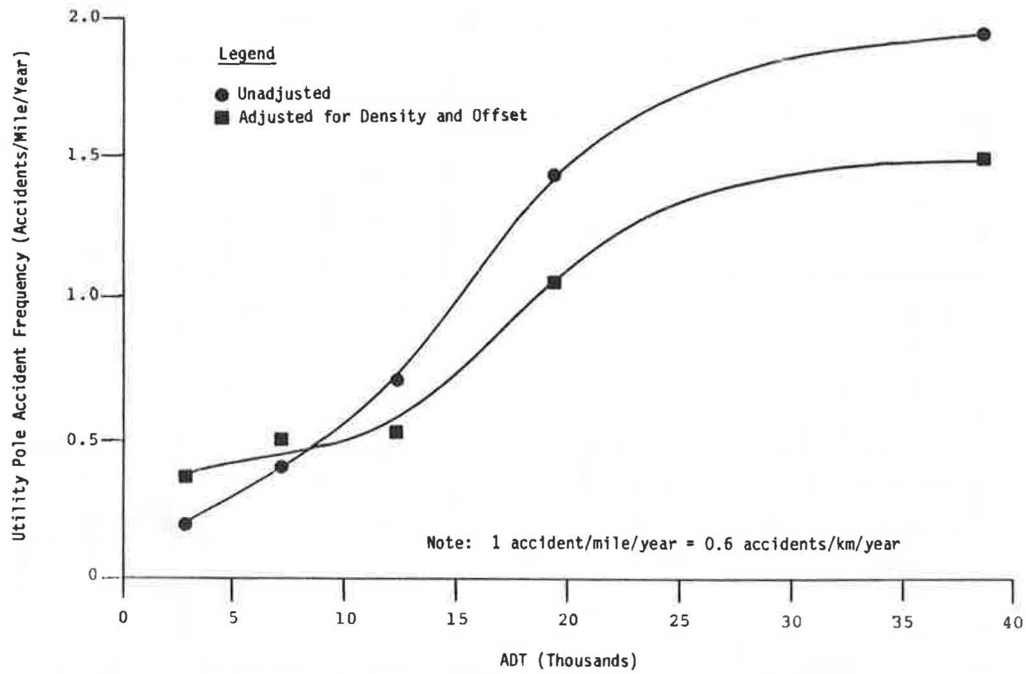



**FIGURE 4** Relationship between frequency of utility pole accidents and ADT.

## Severity of Utility Pole Accidents

Previous investigations have shown that utility-pole-related accidents are more severe than most other single-vehicle roadway accidents. An analysis of the severity data collected for this study was conducted to identify factors that significantly affect the severity of these accidents. Although the percentages of fatal, injury, and property-damage accidents were based on the entire sample of utility pole accidents, it is possible that roadway features or combinations of factors have a significant effect on severity of utility pole accidents.

Efforts were made to identify and quantify the roadway factors that affect the severity of utility pole accidents, primarily through the use of contingency table analysis. In this analysis the chi-square statistic was computed and compared with the critical chi-square value to determine whether a systematic relationship exists between two variables. The roadway variables that appear to have a significant relationship with the severity of utility pole accidents (percentage of injury plus fatal accidents) are horizontal curvature, speed limit, and pole type.

For each of these variables, a further examination of the apparent relationship was conducted to identify specific conditions that affect severity. For example, it was necessary to compare the effect of speed limit on accident severity for various categories of pole types and pole offsets. Thus numerous contingency tables were developed and tested to determine the isolated effects of each roadway and utility pole variable on accident severity.

To illustrate this process, a contingency table was developed for comparing the accident severity for wood and metal poles for various groups of offsets (Table 5). For pole offsets of 1 to 10 ft (0.3 to 3.0 m), accidents involving wood utility poles have a significantly higher severity than accidents involving metal poles (chi-square value of 17.2). This is probably because the metal poles used in the data sample were mostly poles with frangible bases that were designed to reduce accident severity on impact.

An analysis was also conducted to examine the effect of speed limit on severity as a function of several groupings of other variables (pole offset and pole type). No significant relationships were found between speed limit and severity, even though Jones and Baum (1) found that accident severity increased on roads with higher speed limits. One possible reason that speed limit was not found to affect severity in this analysis is that confounding effects may occur, such as (a) the incidence of vehicle rollovers that occur in some utility pole accidents, which often leads to severe accidents, and (b) the vehicle size and weight involved in various accidents can greatly offset severity. Also, the only categories of accident severity in this study were property-damage-only, injury, and fatal, so a more detailed analysis by degree of injury (i.e., A type, B type, and C type injury) was not possible.

Although no significant relationship was found between speed limit and severity of utility pole accidents, accident severity was found to increase significantly with increasing curvature (straight, gentle curves, and sharp curves) for sections with speed limits of 20 to 35 mph (32 to 56 km/h) and 50

**TABLE 5** Contingency Table for Comparing Accident Severity and Pole Type for Pole Offsets of 1 to 10 Feet

| Accident Severity | Pole Type | | | |
|---|---|---|---|---|
| | Wood | | Metal | |
| | Number | Percent | Number | Percent |
| Fatal and Injury | 2,544 | 48.8 | 455 | 41.8 |
| PDO | 2,671 | 51.2 | 633 | 58.8 |

Note: 1 foot = 0.3 m

to 55 mph (80 to 88 km/h). This was not found for speed limits of 40 and 45 mph (64 to 72 km/h), due possibly to limited sample sizes within these ranges or due to the lack of a wide range of curvature in the data base for that speed group.

## DEVELOPMENT AND TESTING OF PREDICTIVE MODEL

One of the objectives of this study was to develop a model to predict expected utility pole accident experience as a function of roadway and utility pole characteristics. Linear and nonlinear regression analysis was used to develop the predictive models. The predictive model was constructed not only to provide the mathematical best-fit of the sample data, but also to provide a logical and systematic tool that could be used to replicate a realistic value for utility pole accidents, given specific site conditions.

The previous analyses (correlation analysis, branching analysis, and analysis of variance and covariance) led to the selection of the dependent and independent variables to be considered in the regression analysis. The annual number of utility pole accidents per mile was selected as the dependent variable. The independent variables selected for initial inclusion in the regression equation were pole density, pole offset, ADT, speed limit, area type, road class, and shoulder type. After testing with numerous combinations of independent variables, it became apparent that pole offset, volume, and pole density collectively explained a high degree of variance in utility pole accidents, and little additional variance could be explained by the addition of other independent variables. These three variables were also desirable for use in the model because they are continuous, which makes them more suitable for regression analysis.

Several linear and nonlinear models were tested to determine if they would provide a better fit of the sample data. Inspection of plots of the dependent variable as a function of the independent variables was used to assist in selecting various nonlinear forms. The relationship between pole offset and accident frequency in particular appears to suggest a hyperbolic relationship between the two variables (as shown in Figures 2 and 3). This relationship is also shown in the encroachment curves developed by Glennon as a function of lateral distance from the edge of the roadway (10).

A summary of some of the linear and nonlinear models developed is given in Table 6, along with their associated regression statistics. After examining each model with respect to the overall significance of the regression statistics (as well as logical relationships), the following models were selected for further examination. The linear model is

$$\text{Acc/Mi/Yr} = 3.52 \times 10^{-5}\ (\text{ADT}) + 0.101\ (\text{DENSITY}) - 0.0415\ (\text{OFFSET}) + 0.52 \quad (1)$$

and the multiplicative model is

$$\text{Acc/Mi/Yr} = [9.84 \times 10^{-5}\ (\text{ADT}) + 0.0354\ (\text{DENSITY}) \div (\text{OFFSET})^{0.6}] - 0.04 \quad (2)$$

TABLE 6 Summary of Regression Statistics

| Type of Model | $R^2$ | Standard Error | F-Statistic | Constant | Independent Variable | Coefficient |
|---|---|---|---|---|---|---|
| Linear | 0.555 | 0.628 | 474 | 1.00 | ADT | $0.345 \times 10^{-4}$ |
| | | | | | Density | $0.892 \times 10^{-2}$ |
| | | | | | Offset | -0.0371 |
| | | | | | Speed Limit | -0.0103 |
| Linear | 0.551 | 0.630 | 623 | 0.52 | ADT | $0.352 \times 10^{-4}$ |
| | | | | | Density | 0.0101 |
| | | | | | Offset | -0.0415 |
| Hyperbolic | 0.630 | 0.572 | 864 | -0.85 | ADT | $0.314 \times 10^{-4}$ |
| | | | | | Density | $0.736 \times 10^{-2}$ |
| | | | | | $(\text{Offset})^{-0.6}$ | 3.6793 |
| Multiplicative | 0.565 | 0.620 | 989 | -0.15 | Density | 0.013 |
| | | | | | ADT/Offset | $0.178 \times 10^{-3}$ |
| Multiplicative | 0.429 | 0.710 | 1146 | 0.36 | $\frac{\text{ADT*Density}}{\text{Offset}}$ | $0.271 \times 10^{-5}$ |
| Multiplicative, Exponential | 0.596 | 0.598 | 1121 | -0.19 | Density | 0.0117 |
| | | | | | $\text{ADT}/(\text{Offset})^{0.7}$ | $0.145 \times 10^{-3}$ |
| Exponential | 0.633 | 0.570 | 873 | -0.72 | ADT | $0.314 \times 10^{-4}$ |
| | | | | | $(\text{Density})^2$ | $0.860 \times 10^{-4}$ |
| | | | | | $(\text{Offset})^{-0.6}$ | 3.6090 |
| Multiplicative, Exponential* | 0.630 | 0.572 | 1295 | -0.04 | $\text{ADT}/(\text{Offset})^{0.6}$ | $0.984 \times 10^{-4}$ |
| | | | | | $\text{Density}/(\text{Offset})^{0.6}$ | 0.0354 |
| Logarithmic | 0.613 | 0.586 | 802 | 1.69 | ADT | $0.314 \times 10^{-4}$ |
| | | | | | Density | $0.734 \times 10^{-2}$ |
| | | | | | LN (Offset) | -0.6516 |
| Logarithmic, Exponential | 0.584 | 0.607 | 2138 | -0.38 | $\frac{\text{LN(ADT)*Log}_{10}\text{(Density)}}{(\text{Offset})^{0.6}}$ | 0.2973 |

*Selected model

As a final step before selecting the regression model, an examination of the residuals was conducted for the linear and multiplicative models. A residual is a deviation of an observed value of the dependent variable (utility pole accidents) from the predicted value obtained by the regression equation. Scatter plots of standardized residuals and standardized values of the dependent variables and independent variables were generated and reviewed. The results indicate that the assumptions of linear regression are valid. Consequently, both models appear to be satisfactory for further use.

Although each models meets the statistical tests, the linear model implies that the accident experience is a sum of the effects due to traffic volume plus the effects due to pole offset plus the effects due to pole density (modified by a constant), with no interactive effects between the independent variables. For example, the effects due to pole offset of 3.0 ft (0.9 m) would be the same if the ADT were 1,000 or 50,000. The multiplicative model is interactive with respect to the independent variables, so the effect due to pole offset takes into account the effects of ADT and pole density when predicting accident experience. Testing of the linear and multiplicative models indicated that the multiplicative model gave more accurate results at the low and high ranges of data values. Both models showed satisfactory predictive capabilities in the middle ranges of data values.

Because of these reasons the multiplicative model was selected to predict accidents and to develop accident reduction factors. The multiplicative model also had a higher explained variance, a lower constant, and a lower standard error. The multiplicative model also appeared to be more logical than the linear model because pole offset, traffic volume, and pole density would not be expected to have additive effects on utility pole accidents, as suggested in the linear model.

Before further testing with the multiplicative model, the range of the independent variables was defined based on the available data base. It was considered important that those limitations not be violated, because extrapolation beyond the range may yield unrealistic results. A brief discussion follows that describes an analysis of the predictive capabilities of the model.

### Comparison of Predicted and Actual Accidents

Before the development of the regression model, nine sites were randomly selected from the data base and set aside for use in validating the predictive model. The nine sections were not used in the development of the model. Pole offset, traffic volume, and pole density data were collected at the nine sites along with accident data as input variables into the regression equation. The model provided a close fit for seven of the nine sites, with two sites yielding a prediction error of more than one standard error. There were four negative and five positive residuals, which provides some evidence that the equation does not have a systematic bias. The algebraic average residual for the nine sites was only +0.003, which was well within the standard error of the regression of 0.57. Overall, these data indicate that the model provides a reasonable prediction of the number of utility pole accidents per mile per year.

### Analysis of Residuals

Based on analysis of the outliers in the total data base (i.e., residuals more than three standard errors from the mean), a sensitivity analysis was conducted of the effects that each independent variable has on the number of utility pole accidents. The results of this analysis indicate that the actual variation in the frequency of utility pole accidents in the data base was greatest where utility pole accidents are high. For example, for volumes greater than 20,000, with pole offsets less than 3 ft (1.0 m) and pole densities greater than 35 poles per mile (22 poles/km), the absolute spread in utility pole accidents was greater than at low volumes, low pole densities, and high pole offsets.

A summary was made of the actual and predicted utility pole accidents from sections in the data base that fell within those ranges. The predictive equation did not appear to have a systematic bias because the model overpredicted for some sites and underpredicted at others, and the algebraic average residual for the 31 sites was -0.107. Thus the model predicts an average value of utility pole accidents for this range of conditions.

### Comparison to Analysis of Covariance Results

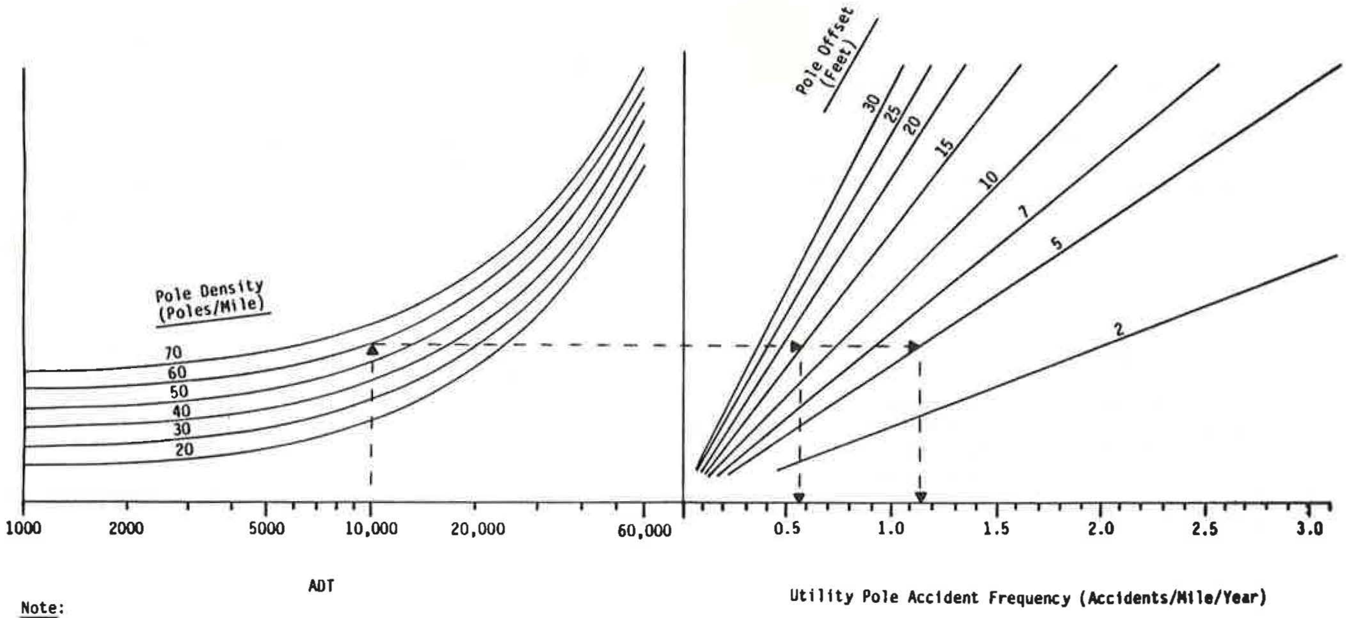
In another approach to evaluate the capabilities of the predictive model, a comparison was made between the regression results and the analysis of covariance results for 15 randomly selected test cases. First, several general pole offset, volume, and density conditions were specified and used in the regression model, as well as in the analysis of covariance graph given in Figure 4. The results of this analysis indicated that the predictive model yields reasonably close results to the analysis of covariance results developed from actual conditions.

In summary, the comparison between the nine test sites and the analysis of residuals indicates the model has satisfactory predictive capabilities within the specified range of the input variables. The model appears to provide a valid representation of the data base collected for this study. However, it should be understood that accident data may vary considerably between sites with basically similar conditions because of random accident occurrences. Thus even the best predictive models may not accurately predict accidents at all sites. However, the model appears to be a relatively good predictor of utility pole accidents and is useful for estimating average expected utility pole accidents for a range of conditions.

### Application of Predictive Model

To illustrate the utility pole accident predictive model under a variety of conditions, a nomograph was developed from the model (Figure 5). Based on volume, pole density, and pole offset, the nomograph can be used to obtain the approximate frequency of utility pole accidents that would be computed by using the model. For example, to compute the utility pole accidents on a roadway with an ADT of 10,000, a pole density of 60 poles per mile (37 poles/km), and pole offsets of 5 ft (1.5 m), enter the nomograph at the 10,000 ADT scale. Proceed up and turn horizontally at the 60 poles per mile curve and cross the 5-ft (1.5-m) offset line. Then proceed down and read 1.14 utility pole acc/mi/yr (0.71 acc/km/yr).

By using the nomograph with various combinations of volume, pole offset, and pole density, it is easy to determine the sensitivity of the model to any of the three factors. In the previous example, changing the offset to 15 ft (4.6 m) would reduce the expected accidents from 1.14 to about 0.57 (0.71 to




Note:

1 foot = 0.3 meter
1 pole/mile = 0.6 poles/km
1 accident/mile/year = 0.6 accidents/km/year

FIGURE 5 Nomograph for predicting accident frequency developed for predictive model.

0.35 acc/km/yr), a 50 percent reduction. The effect of changing both the pole density and pole offset can be determined as well.

## CONCLUSIONS

The following conclusions are based on the results of the accident analysis.

1. The variables that were of primary importance in explaining the variation in utility pole accident experience were traffic volume (ADT), pole offset, and pole density. The frequency of utility pole accidents increases significantly with increases in traffic volume. Utility pole accidents decrease significantly with increasing pole offsets and increase significantly with pole densities (0.001 level of confidence in each case). When controlling for these three variables, other variables that have a significant impact on utility pole accident experience (although to a lesser degree) include roadway class (two-lane, four-lane divided, four-lane undivided, and so forth), shoulder width, horizontal curvature, roadway lighting, and speed limit.
2. By using contingency table analysis, several conclusions were made regarding the effect of roadway variables on the severity of utility pole accidents. For sections with pole offsets of 1 to 10 ft (0.3 to 3.0 m), wood poles were associated with significantly higher severities than metal poles. This is probably because most of the metal poles in the data base were luminaire poles with frangible bases. Speed limit was found to have no significant effect on the severity of utility pole accidents for the data base in this study. This may be due partly to the fact that detailed data by degree of injury were not available. Accident severity was found to increase with increasing roadway curvature for some speed limit categories.
3. Linear and nonlinear regression analyses were used to develop a model to predict utility pole accident experience as a function of roadway and utility pole characteristics. An interactive model was developed to predict the frequency of utility pole accidents, accidents per mile per year as a function of ADT, pole offset, and pole density. The model has an r value of 0.79 ($r^2 = 0.63$), a low constant (-0.04), and a low standard error (0.572). The model was validated in several ways, including the use of independent roadway sections from four states covering a range of roadway and traffic conditions. The model showed good predictive capabilities within the specified range of input variables, including ADTs of 1,000 to 60,000, pole offsets of 2 to 30 ft (0.6 to 9.0 m), and pole densities of 10 to 90 poles per mile (6 to 56 poles/km). A nomograph was developed based on the model to allow for graphical determination of expected utility pole accident experience and countermeasure effectiveness.

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