대한교통학회 제32회 학술발표회

Development of safety-Based Guidelines for Cost-Effective Utility Pole Treatment along Highway Rights-of-way

교통개발연구원

김 정 현

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Abstract

This study was conducted to develop a methodology to predict utility pole accident rates and to evaluate cost-effectiveness for safety improvement for utility pole accidents. The utility pole accident rate prediction model was based on the encroachment rate approach introduced in the Transportation Research Board Special Report 214. The utility pole accident rate on a section of highway depends on the roadside encroachment rate and the lateral extent of encroachment. The encroachment rate is influenced by the horizontal and vertical alignment of the highway as well as traffic volume and mean speed. The lateral extent of encroachment is affected by the horizontal and vertical alignment, the mean speed and the roadside slope. An analytical method to generate the probability distribution function for the lateral extent of encroachment was developed for six kinds of encroachment types by the horizontal alignment and encroachment direction. The encroachment rate was calibrated with the information on highway and roadside conditions and the utility pole accident records collected on the sections of 55mph speed limit of the State Trunk Highway 12 in Wisconsin. The encroachment rate on a tangent segment was calibrated as a function of traffic volume with the actual average utility pole accident rates by traffic volume strategies. The adjustment factors for horizontal and vertical alignment were then derived by comparing the actual average utility pole accident rates to the estimations from the model calibrated for tangent and level sections.

A computerized benefit-cost analysis procedure was then developed as a means of evaluating alternative countermeasures. The program calculates the benefit-cost ratio and the percent of reduction of utility pole accidents resulting from the implementation of a safety improvement. This program can be used to develop safety improvement alternatives for utility pole accidents when a predetermined performance level is specified.

CHAPTER I. INTRODUCTION

An extensive effort has been made in recent years to improve highway safety. To accomplish this, a major emphasis has been placed on the elimination of hazardous roadside conditions. Especially, extensive consideration has recently been given to the development of countermeasures to reduce or eliminate accidents involving fixed objects including utility poles. Utility poles have been identified as one of the major roadside hazards, and many studies have been conducted for utility accommodation within the highway rights-of-way.

The guidelines in the "Roadside Design Guide" (1) by the American Association of State Highway and Transportation Officials (AASHTO) published in 1988 provides a practical approach to roadside design for safety. The policy depends on traffic and geometric conditions, and other roadside conditions along the roadway.

Roadside safety improvements compete for limited highway funds with many other needed improvements. The decision for the improvement should then be cost-effective to produce maximum benefit with minimum cost. The policies for treatment of existing utility poles or placement of new utility poles in new highway construction should be developed in the same manner. In order to achieve this, accurate accident rate prediction under various roadway and roadside conditions, relative severity and cost estimation, and use of appropriate benefit-cost analysis procedures are required.

The current guidelines or methodologies were based on an empirical approach with the data collected in several states. However, the amount of data was limited, and no consideration was given to the effect of highway alignment or roadside slope. In addition, accident rates vary state by state. For these reasons, the objective of this research was to develop an analytical method which does not require extensive effort for data collection, and can be applied under site-specific conditions in Wisconsin.

To achieve this objective, the following tasks were formulated:

1. Develop an analytical methodology to generate the probability distribution function for lateral extent of roadside encroachment which can be used in the utility pole accident rate prediction model.
2. Prepare a utility pole accident rate prediction model which uses the probability distribution function for lateral extent of encroachment generated above.
3. Predict utility pole accident rates under various roadway and roadside conditions.
4. Examine the cost-effectiveness of safety improvement alternatives under a range of roadway/roadside conditions.
5. Develop a methodology for utility pole treatment policy for utility pole accidents.

The encroachment model approach presented in TRB Special Report 214 (2) was employed for accident rate prediction, and the model was calibrated with utility pole accident data collected in the State Trunk Highway 12 of Wisconsin. Information on roadside conditions was collected using WisDOT's photologs and datalogs. Current countermeasures for utility pole accidents were reviewed and the safety improvement alternatives which would be considered in this study were specified. The accident rate for each alternative was predicted, and the cost for each alternative was compared with the benefit from the accident reduction. Recommendations for utility pole placement were then developed using the procedure.

CHAPTER II
UTILITY POLE ACCIDENT RATE PREDICTION MODEL

II-1. Structure of Model

The mathematical structure of the number of accidents to a utility pole prediction model which was used in this study has been introduced in the TRB Special Report 214 (3) as follows:

$$Ex(A_h) = Ex(E)\,Pr(E_h/E)\,Pr(C_h/E_h)\,Pr(A_h/C_h) \quad \text{Eq. 2.1}$$

where, $Ex(A_h)$ = expected annual number of roadside accidents involving a specific hazard (h),

$Ex(E)$ = expected annual number of encroachments on the highway segment encompassing the hazard (typically 1 mile long),

$Pr(E_h/E)$ = conditional probability that, given an encroachment, its location is such that an impact with the hazard is possible,

$Pr(C_h/E_h)$ = conditional probability that, given an encroachment in the potential impact area, a collision between vehicle and object will occur, and

$Pr(A_h/C_h)$ = conditional probability that, given a collision, its severity will be so great as to result in an accident.

The first required element of the model is Ex(E), the expected annual number of encroachment per mile of highway is assumed as

$$Ex(E) = [Ex(EXC)/2]\,[1 + Pr(Y \geq L)] \quad \text{Eq. 2.2}$$

where, $Ex(EXC)$ = expected annual number of lane encroachments per mile, and

$Pr(Y \geq L)$ = probability that an errant vehicle, veering to the left, will cross the adjacent lane of width, L, and encroach on the roadside.

The expected number of encroachments, Ex(EXC), is assumed to be related to traffic volume for given speed limit and geometrics as follows:

$$Ex(EXC) = a(ADT)^b \qquad \text{Eq. 2.3}$$

where, ADT = two-directional average daily traffic volume (veh/day), and
a, b = calibration constants.

The probability, $\Pr(Y \geq L)$ can be assumed as one-parameter exponential distributions such as:

$$\Pr(Y \geq y) = e^{c(y)} \qquad \text{Eq. 2.4}$$

where, c = constant, and
y = lateral extent of encroachment.

The conditional probability, $\Pr(E_h /E)$ that, given an encroachment, and can be expressed by the ratio of the length of potential hazard along a roadway to a 1.0-mile length of highway segment.

$$\Pr(E_h /E) = X / 5{,}280 \qquad \text{Eq. 2.5}$$

where, X = length of potential hazard due to an object along the highway.

The mathematical expression of $\Pr(C_h /E_h)$, the conditional probability that, given an encroachment in the potential impact area, a collision between vehicle and object will occur is:

$$\Pr(C_h / E_h) = \Pr(Y \geq y) \qquad \text{Eq. 2.6}$$

The definition and the probability function of this element are the same as in Equation 2.4 .

The final necessary components of the model is $\Pr(A_h / C_h)$, the conditional probability of a reportable accident given a collision. The TRB Special Report 214 (2) presents a usable probability estimate for utility pole to be 0.90.

II-2. Lateral Extent of Encroachment

The number of accidents to a utility pole is affected by the probability that the lateral (perpendicular to the edge of roadway) extent of roadside encroachment is equal to or greater than the lateral offset of the utility pole. The probability is influenced by vehicle speed, roadway and roadside geometrics.

The minimum lateral extent of roadside encroachment can be estimated by the braking distance of the errant vehicle. The braking distance is usually expressed as:

$$d = V^2 / [\, 30\,(f \pm G)\,] \qquad \text{Eq. 2.7}$$

where, d = braking distance,
V = encroachment speed,
f = friction coefficient, and
G = slope (%/100).

The slope, G, in Equation 2.7 means the actual grade of the encroachment trajectory, and is determined by not only the roadway grade but also the roadside slope. When the roadside slope is S:1 and the vertical grade of highway is G percent, the grade of the encroachment trajectory, G_E is calculated as:

G_E = 100 sinϕ (1/*S* + *G*/100 tanϕ) .... Eq. 2.8

where, G_E = grade of encroachment trajectory (%),

1/S = roadside slope (+ for cut slope; - for fill slope; 0 for level roadside),

ϕ = encroachment angle (deg), and

G = roadway grade (%).

For the far-side encroachments, the actual grades of encroachments on the adjacent lanes are necessarily grades of (Gcosϕ) %. When the roadside to a utility pole is composed of variable slopes, the lateral extent of encroachment can be calculated as done for far-side encroachments.

2-1. Near-side Encroachment on Tangent

The minimum encroaching distance on the roadside is calculated by

$$d = \frac{V^2}{30(f_2 \pm G_2)} \qquad \text{Eq. 2.9}$$

and the lateral extent is then calculated as:

$$l = d\left(\frac{\frac{1}{G_2}}{\sqrt{1+(\frac{1}{G_2})^2}}\right)\sin\phi = \left(\frac{V^2}{30(f_2 \pm G_2)}\right)\left(\frac{\frac{1}{G_2}}{\sqrt{1+(\frac{1}{G_2})^2}}\right)\sin\phi \qquad \text{Eq. 2.10}$$

where, f_2 = friction coefficient on roadside,

G_2	=	grade for encroachment on roadside,
l	=	minimum lateral extent of encroachment (ft), and
ϕ	=	encroachment angle (deg).

2-2. Far-side Encroachment on Tangent

The minimum traveling distance of the encroachment beyond roadway, *d*, can be calculated as shown in Figure 5.5. It can be expressed as:

$$d_2 = \frac{V_1^2 - (w\sin\phi)(30f_1 \pm G_1)}{30(f_2 \pm G_2)} \quad \text{..} \quad \text{Eq. 2.11}$$

where, d_2 = minimum encroaching distance on roadside (ft),
V_1 = vehicle operating speed before the encroachment occurs (mph),
w = lane width of adjacent lane (ft),
f_1 = friction coefficient on roadway,
G_1 = grade for encroachment on adjacent lane,

and the lateral extent is calculated by Equation 2.10 with d_2, the result of Equation 2.11.

2-3. Near-side Encroachment to the Inside of a Horizontal Curve

When the encroachment occurs from the inside lane to the inside of a horizontal curve, the lateral extent of encroachment is:

$$l = (R-w) - \sqrt{(R-w)^2 + d^2 - 2(R-w)d\sin\phi} \quad \text{.........................} \quad \text{Eq. 2.12}$$

where, R = radius of horizontal curve (ft).

2-4. Far-side Encroachment to the Inside of a Horizontal Curve

When encroachment occurs from the outside lane of a roadway on a horizontal curve into the inside of the horizontal curve, the minimum length of the encroachment trajectory is expressed as in Equation 2.13 and the minimum lateral extent can be calculated with Equation 2.14.

$$d = \left[R\sin\phi - \sqrt{R^2\sin^2\phi - R^2 + (R-w)}\right] + \left[\frac{V_1^2 - d_1 30(f_1 \pm G_1)}{30(f_2 \pm G_2)}\right] \quad \ldots\ldots \quad \text{Eq. 2.13}$$

$$l = (R-w) - \sqrt{R^2 - 2Rd\sin\phi + d^2} \quad \ldots\ldots \quad \text{Eq. 2.14}$$

2-5. Near-side Encroachment to the Outside of a Horizontal Curve

The minimum lateral extent of encroachment by a vehicle traveling the outside lane into outside of a horizontal curve is obtained with the minimum encroaching distance on the roadside from Equation 2.9. The result can be expressed as:

$$l = \sqrt{(R+w)^2 + d^2 + 2(R+w)d\sin\phi} - (R+w) \quad \ldots\ldots \quad \text{Eq. 2.15}$$

2-6. Far-side Encroachment to the Outside of a Horizontal Curve

The minimum travel distance on a roadside for far-side encroachment to the outside of a horizontal curve is expressed as:

$$d = \left[\sqrt{(R+w)^2 - R^2 + R^2\sin^2\phi} - R\sin\phi\right] + \left[\frac{V_1^2 - d_1 30(f_1 \pm G_1)}{30(f_2 \pm G_2)}\right] \quad \ldots\ldots \quad \text{Eq. 2.16}$$

and the minimum lateral extent can be calculated by Equation 2.17.

$$l = \sqrt{R^2 + 2Rd\sin\phi + d^2} - (R + w) \qquad \text{Eq. 2.17}$$

2-7. Lateral Extent of Encroachment on Roadside of Various Slopes

When the roadside to a utility pole is composed of variable slopes, the minimum lateral extent of encroachment can be calculated as done for far-side encroachments. The length of the encroachment trajectory on the second slope is:

$$d_2 = \frac{V_1^2 - \left[l_1\sqrt{(1/\sin\phi)^2 + (1/G_1)^2}\right][30(f_2 \pm G_1)]}{30(f_2 \pm G_2)} \qquad \text{Eq. 2.18}$$

where, d_2 = minimum encroachment distance on the 2nd roadside slope (ft),
V_1 = vehicle operating speed before encroachment occurs (mph),
l_1 = width of the first roadside slope (ft),
G_1 = grade for encroachment on the first roadside, and
G_2 = grade for encroachment on the second roadside.

The lateral extent of the encroachment is the summation of the lateral distance of the first slope and the lateral extent of encroachment on the second slope calculated by Equation 2.10 with the result from Equation 2.18. For the encroachment on a horizontal curve, Equation 2.12 or 2.15 can be used instead of Equation 2.10.

For far-side encroachments on variable roadside slopes, the travel distance on the adjacent lane is (w/sinϕ) when the lane width is w and the encroachment angle is ϕ. The encroachment speed at the edge of the traveling lane is expressed as:

$$V_2 = \sqrt{V_1^2 - (w / \sin\phi)(30 f_1)} \qquad \text{Eq. 2.19}$$

where, V_2 = vehicle speed on the edge on roadway (mph), and

V_1 = vehicle operating speed before encroachment (mph).

On horizontal curves, the same method can be applied with Equations 2.14 and 2.15 instead of Equation 2.10.

II-3. Probability Distribution Function for Lateral Extent of Encroachment

There is some variation in encroachment speed even though it is assumed that the vehicle is operated at mean speed, and the encroachment angle also varies. McCoy et al. (3) divided the range of encroachment angles into six intervals and presented the probability of each according to the results of a field survey (4). Encroachment speeds are assumed to be normally distributed with the standard deviation of five mile per hour. The range of encroachment speeds is divided into five intervals based on the mean speed on the roadway. Thus, 30 combinations of encroachment angle and speed are evaluated. A sample probability table is given in Table 2.1 with a speed limit of 55mph.

Seven levels of roadside slopes are selected in this study such as cut 3:1, cut 5:1, cut 10:1, level, fill 10:1, fill 5:1, and fill 3:1. Five levels of vertical grades, -4%, -2%, level, +2%, and +4%, are also chosen. For horizontal curvature, 2°, 4°, 7°, and 10° are picked. One hundred seventy five tables for lateral extents of encroachments for six kinds of encroachments corresponding to Table 2.1 can then be prepared assuming a 55mph speed limit, 12-foot lane width, and 0.60 of friction coefficient for the roadway, and 0.50 for the roadside, ignoring the cross slopes of roadway pavement. The friction coefficient of the roadway, 0.60, is from the weighted average value obtained from the roadway surface conditions of 900 utility pole accidents in Wisconsin for three years. but the accident

Table 2.1 Probability of Each Encroachment Speed and Angle Combination under 55mph Speed Limit

	Angle (°)	5	10	15	20	25	30
Speed (mph)	Probability	0.48	0.20	0.12	0.08	0.05	0.07
45.0	0.0606	0.0291	0.0121	0.0073	0.0049	0.0030	0.0042
50.0	0.2306	0.1107	0.0461	0.0277	0.0185	0.0115	0.0161
55.0	0.4176	0.2005	0.0835	0.0501	0.0334	0.0209	0.0292
60.0	0.2306	0.1107	0.0461	0.0277	0.0185	0.0115	0.0161
65.0	0.0606	0.0291	0.0121	0.0073	0.0049	0.0030	0.0042

records regarded those surface conditions in the same category. The value of 0.50 is the representative value for the roadsides covered by small gravel, as assumed in Glennon and Wilton's study (4).

The probability function for lateral extent of encroachment is then generated by preparing a table as shown in Table 2.2. The third column of Table 2.2 is the minimum lateral extent of encroachment, and the fourth column is the probability that the minimum lateral extent of encroachment occurs. Probabilities that the lateral extents of encroachments are equal to or greater than certain distances are obtained by accumulating the probabilities that the minimum lateral extent of encroachments are equal to or greater than the distance as shown on Column 5. Each cumulative probability set can be expressed by an exponential function. Figure 2.1 shows the probability distribution function for lateral extent of encroachment on tangent and level section of highway with level roadside. The average R-square values of regressions for 175 functions are 0.95.

For each type of encroachment, the exponent shows a linear relationship to the curvature, grade, and roadside slope so that the probability distribution functions by encroachment types can be stated as:

Table 2.2 Generation of Probability Distribution Function for Lateral Extent of Encroachment (Curvature = 0deg; Grade = 0%; Roadside Slope = level; Near-side Encroachment)

Speed (mph)	Encroach Angle (deg)	Min. Lateral Extent (ft)	Probability	Cumulative Probability	ln (Probability)
65	30	140.80920	0.004242	0.004242	-5.462720
60	30	119.97950	0.016142	0.020384	-3.893005
65	25	119.01650	0.003030	0.023414	-3.754421
60	25	101.41050	0.011530	0.034944	-3.354009
55	30	100.81610	0.029232	0.064176	-2.746126
65	20	96.31824	0.004848	0.069024	-2.673301
55	25	85.21297	0.020880	0.089904	-2.409013
50	30	83.31907	0.016142	0.106046	-2.243882
60	20	82.06998	0.018448	0.124494	-2.083498
65	15	72.88726	0.007272	0.131766	-2.026728
50	25	70.42394	0.011530	0.143296	-1.942843
55	20	68.96158	0.033408	0.176704	-1.733279
45	30	67.48845	0.004242	0.180946	-1.709557
60	15	62.10512	0.027672	0.208618	-1.567250
45	25	57.04339	0.003030	0.211648	-1.552831
50	20	56.99304	0.018448	0.230096	-1.469259
55	15	52.18555	0.050112	0.280208	-1.272223
65	10	48.90177	0.012120	0.292328	-1.229879
45	20	46.16436	0.004848	0.297176	-1.213431
50	15	43.12856	0.027672	0.324848	-1.124398
60	10	41.66778	0.046120	0.370968	-0.991639
55	10	35.01251	0.083520	0.454488	-0.788584
45	15	34.93413	0.007272	0.007272	-0.772710
50	10	28.93596	0.046120	0.046120	-0.677510
65	5	24.54425	0.029088	0.536968	-0.621817
45	10	23.43813	0.012120	0.549088	-0.599496
60	5	20.91344	0.110688	0.659776	-0.415855
55	5	17.57310	0.200448	0.860224	-0.150562
50	5	14.52322	0.110688	0.970912	-0.029519
45	5	11.76381	0.029088	1.000000	0.000000

ln (cumulative probability) = (c) (lateral extent of encroachment)

$\ln(\Pr[x \geq y]) = -0.02956\ (y)$

$\Pr(x \geq y) = e^{-0.02956y}$ $R^2 = 0.963$

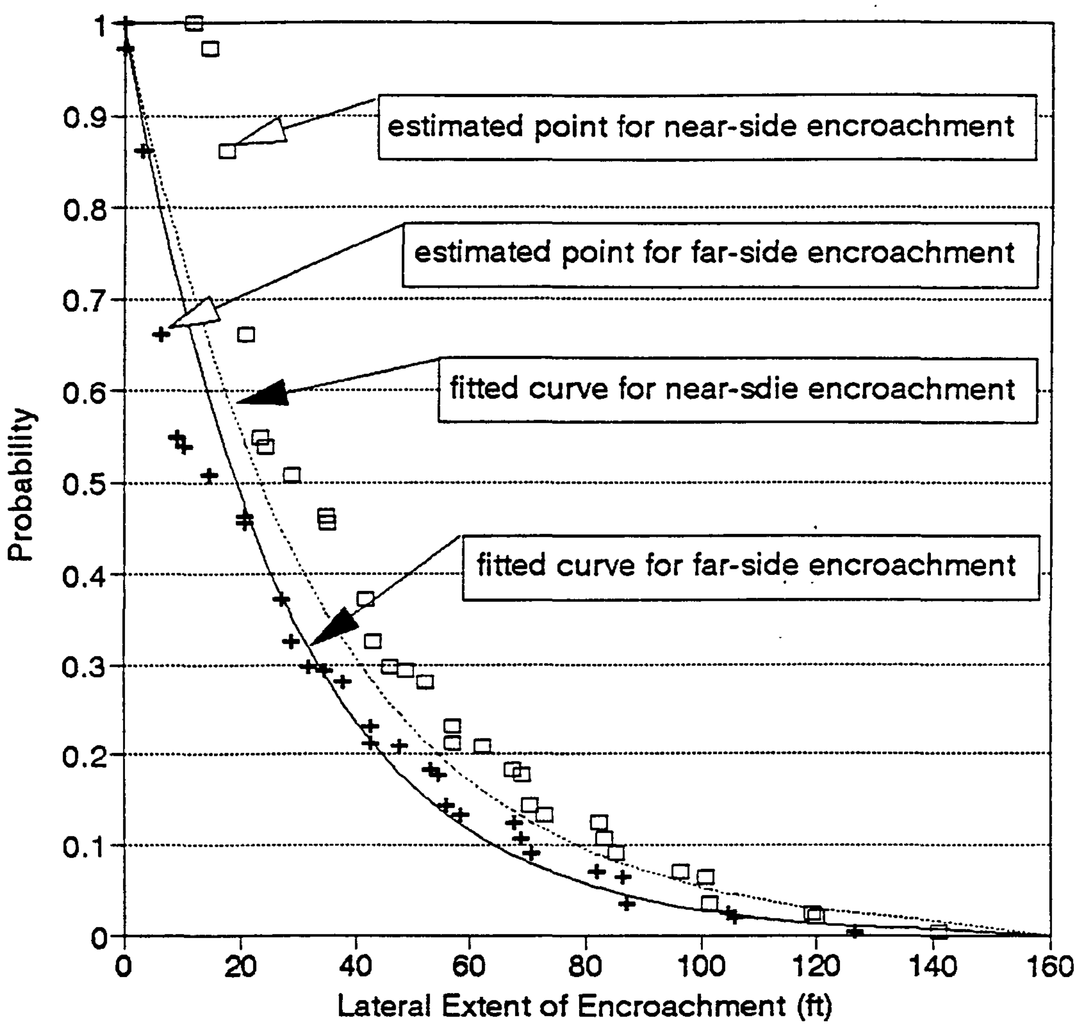


Figure 2.1 Probability Distribution Function for Lateral Extent of Encroachment (tangent; level; level roadside)

$$c = a_1 + [\, a_2 \times Curvature \,] + [a_3 \times Grade] + [\, a_4 \times (\, 1/\,Slope) \,] \quad \text{...... Eq. 2.20}$$

where, c = coefficient of exponent in exponential function, and

a_1, a_2, a_3, a_4 = regression coefficients,

and the results are shown in Table 2.3.

Table 2.3 Probability Distribution Functions for Lateral Extent of Encroachment
(G = grade (%) ; 1/S = roadside slope ; D = Degree of Curvature)

Encroachment Type	Exponent of Probability Distribution Function (c of e^{cy})	R^2
Tangent-Near	-0.0300 - (0.000558 x G) - (0.0261 x (1/S))	0.998
Tangent-Far	-0.0367 + (0.000778 x G) + (0.0337 x (1/S))	0.997
Curve-Near-In	-0.0249 - (0.00274 x D) - (0.000395 x G) - (0.0217 x (1/S))	0.971
Curve-Far-In	-0.0297 - (0.00359 x D) + (0.00631 x G) - (0.0318 x (1/S))	0.990
Curve-Near-Out	-0.0283 + (0.000742 x D) - (0.000524 x G) - (0.0200 x (1/S))	0.991
Curve-Far-Out	-0.0346 + (0.000963 x D) + (0.000597 x G) - (0.0267 x (1/S))	0.993
Note : (1/Slope) = 0 for level roadside slope ; (+) for cut slope and (-) for fill slope		

II-4. Model Application

In the application of the utility pole accident rate prediction model described above, it is necessary to give some treatment to the envelopment of hazard. The offset of the utility pole to the near-most front fender of the colliding vehicle varies with the specific location of impact in Zones 2 and 3 as shown in Figure 2.2. The offset for Zone 3 impacts can be assumed to occur at the midpoint location. Similar treatment can be given to Zone 2 by dividing into six, one foot strips and using the midpoint offset of each strip (2). Table 2.4 shows this procedure. The angles of near-side and far-side encroachments are assumed to be 6.1 deg and 11.5 deg (3)

Thus, the expected annual number of accidents with a utility pole is:

$$Ex(A_p) = \frac{a(ADT)^b}{23{,}467}[\sum_{i=1}^{8} x_i \Pr(Y \geq y_i) + \sum_{j=1}^{8} x_j \Pr(Y \geq y_j)] \quad \text{Eq. 2.21}$$

where, $Ex(A_p)$ = expected annual number of accidents with a utility pole,
y = lateral offset of utility pole (ft), and
i, j = segment number for near or far-side encroachment.

Table 2.4 Length of and Offset to Utility Pole (from Figure 2.2)

Zone	Segment Number	Near-side Encroachment Hazard Length (ft)	Near-side Encroachment Offset (ft)	Far-side Encroachment Hazard Length (ft)	Far-side Encroachment Offset (ft)
1	1	0.67	y	0.67	y + 12.00
2	2	9.41	y + 0.50	5.02	y + 12.49
2	3	9.41	y + 1.49	5.02	y + 13.47
2	4	9.41	y + 2.48	5.02	y + 14.45
2	5	9.41	y + 3.48	5.02	y + 15.43
2	6	9.41	y + 4.47	5.02	y + 16.41
2	7	9.41	y + 5.47	5.02	y + 17.39
3	8	6.27	y + 6.30	3.34	y + 18.21

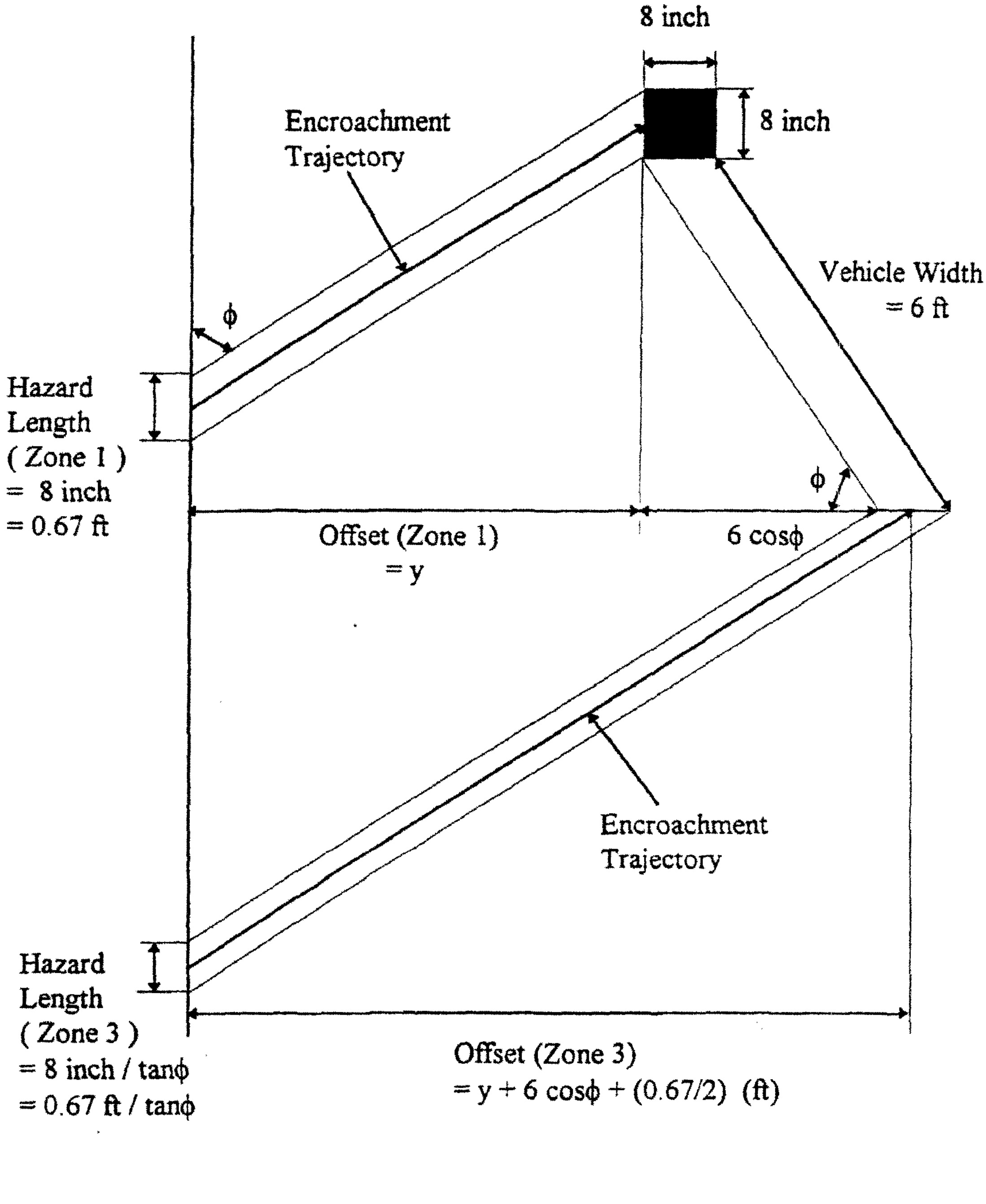


Figure 2.2 Lateral Offset and Hazard Length of Segments for Utility Pole Accident Analysis

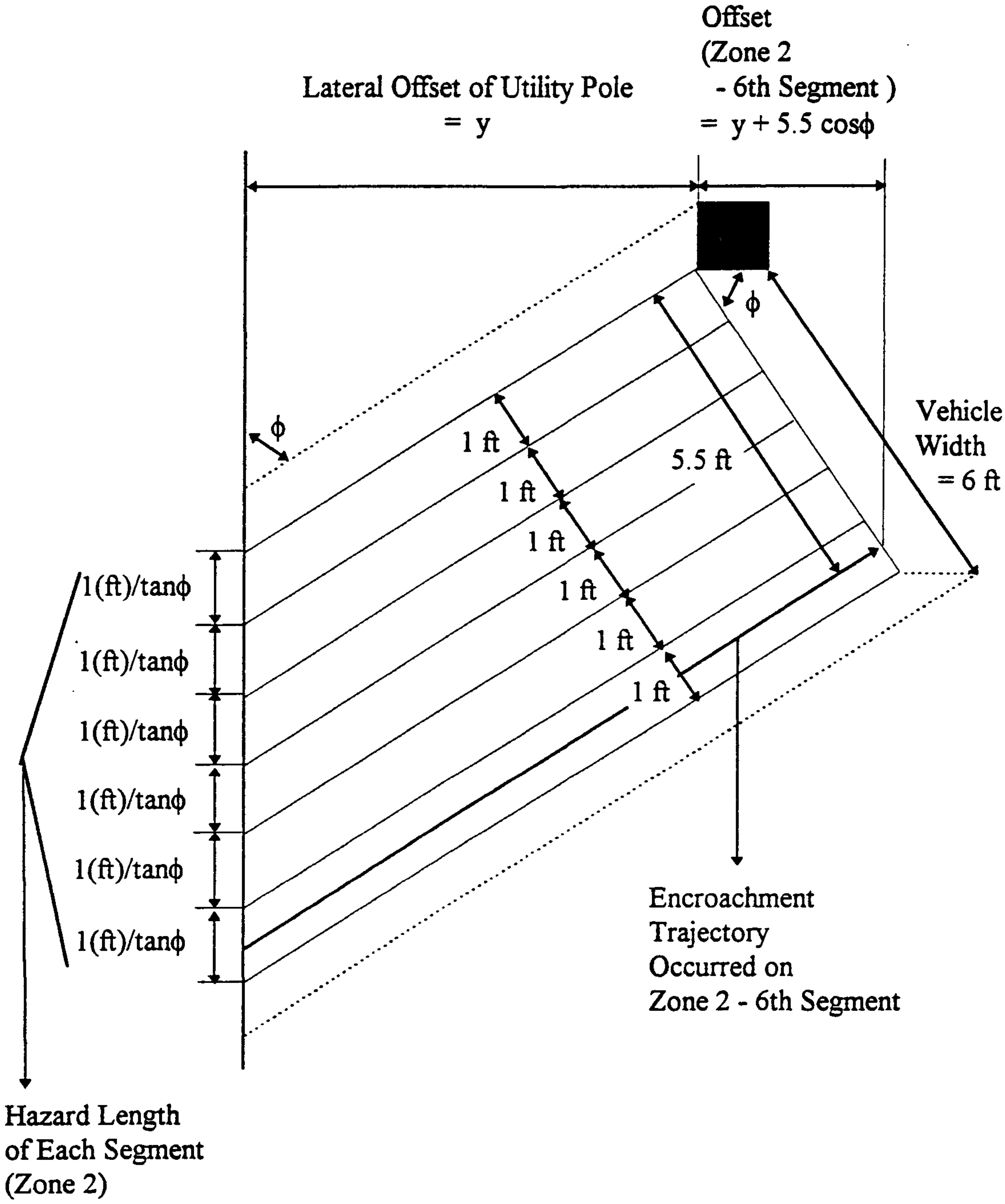


Figure 2.2 (continued)

CHAPTER III. MODEL CALIBRATION

III-1. Data Collection for Roadway and Roadside Conditions

In order to identify the homogeneous highway segments, it is necessary to collect information on roadway and roadside conditions. The homogeneous highway segment should have the same horizontal and vertical alignment, traffic volume, lateral offset and density of utility pole, and roadside slope.

Highway alignment information - horizontal curvature and vertical grade - was obtained from datalog analysis. The other information on roadway and roadside conditions could be obtained from WisDOT's photolog files. It can be a source for the lateral offset and the density of utility pole, the lane width, and roadside slope.

The database was developed with the data collected on STH012 of Wisconsin. From a section of the highway through nine counties (four districts), the selections were made and the sections were divided into 389 homogenous segments by horizontal curvature, vertical grade, utility pole offset, roadside slope, and traffic volume. The number of utility poles on each segment was also included in the database.

III-2. Accident Data Collection

According to the WisDOT's accident record database, 139 utility pole accidents occurred on the selected highway sections from 1988 to 1995. One hundred three accidents occurred on tangent segments, 11 on curves placing utility poles inside the curves and 20 on curves placing poles outside.

III-3. Model Calibration

3-1. Model Calibration for Tangent and Level Segments

The segments of curvatures less than 0.5deg and grades between -2% to +2% were assumed to be level and tangents. The segments were stratified by ADT in 1000-veh/day increments, and the average number of accidents with a utility pole for a year were calculated in Column 4 of Table 3.1 for each ADT range. The remaining terms of Equation 2.21, except the number of encroachments, were also calculated in Column 5. With the values in Column 4 and 5, Equation 2.21 could be expressed as:

$$\begin{aligned} \ln(\mathrm{Ex(EXC)}) &= \ln(\mathit{Column\ 4} \,/\, \mathit{Column\ 5}) \\ &= \ln(a(ADT)^b) \\ &= \ln a + b \ln(ADT) \qquad \text{Eq. 3.1} \end{aligned}$$

The result of the linear regression analysis is:

$$Ex(EXC) = 0.001162\,(ADT)^{0.9141} \qquad \text{Eq. 3.2}$$

3-2. Adjustment Factor for Horizontal Curvature

The adjustment factors are obtained by comparing the actual average number of accidents to a utility pole from the database and the estimated number of accidents to a utility pole calculated from the model, calibrated with the data on tangent segments, by each curvature range. Two types of adjustment factors were derived for encroachment to inside and outside of curves.

As shown in Table 3.2, the second column is the average number of accident to a utility pole by curvature ranges, and the third column is the estimation from the model calibrated for tangent segments. The fourth column is the ratio of Columns 2 and 3. When the ratio for tangent segments, 1.23 is set to 1.0, the ratios for the other curvature ranges were normalized. When the normalized values were set as the dependent variables varying by the independent variables of median values of curvature ranges, a linear regression

Table 3.1 Calibration of Utility Pole Accident Rate Prediction Model

(Tangent and Level Segments Only)

1	2	3	4	5	6
ADT	No. of Utility Pole Accident *	Total # of Utility Poles	# Accident / Pole / year ($Ex(A_p)$)	Average of 2nd Term of Equation 5.22 (terms in bracket / 23467)	Ex(EXC) (col 4 / col 5)
1500	7	303	0.0029	0.001718	1.6811
2500	4	338	0.0015	0.001565	0.9450
3500	1	93	0.0013	0.001257	1.0692
4500	6	125	0.0060	0.001612	3.7226
5500	16	271	0.0074	0.001665	4.4312
6500	4	107	0.0047	0.001802	2.5934
7500	7	220	0.0040	0.001646	2.4170
8500	2	82	0.0030	0.001463	2.0837
9500	11	110	0.0125	0.001485	8.4167
10500	5	34	0.0184	0.001730	10.6232
12500	22	134	0.0205	0.001949	10.5304
15500	2	21	0.0119	0.001973	6.0344

* Number of utility pole accidents for 8 years

LN(Ex) = LN a + b LN(ADT) Ex = a (ADT)^b

= -6.76+ 0.9141 LN(ADT) = 0.001162 (ADT)$^{0.9141}$

R^2 = 57.8%

equation could be acquired. The estimation from the regression equation is the adjustment factor for the encroachment to inside of the curve by each horizontal curvature. This feature is shown in Figure 3.1. The same process was employed for the derivation of curvature adjustment factors for the encroachment to the outside of the curve. Table 3.3, and Figure 3.2 are for the encroachment to the outside of the curve.

With the assumption above, the results were as follows:

$$A_{curve\text{-}in} = \begin{cases} 0.216\,(D) + 1.0 & D \leq 5.0\text{deg} \quad (R^2 = 0.831) \\ 2.080 & D > 5.0\text{deg} \end{cases} \qquad \text{...... Eq. 3.3}$$

Table 3.2 Comparison of Utility Pole Accident Rate to Inside of Horizontal Curve to Estimation

Horizontal Curvature (deg)	Actual Average # Accidents / Utility Pole / Year (Ea)	Average Expected # Accidents (Ex (A_p))	Ea / Ex(A_p)	Normalized Ratio
$0 \le D < 1$	0.006217	0.005070	1.23	1.23/1.23 = 1.00
$1 \le D < 2$	0.010135	0.007506	1.35	1.35/1.23 = 1.10
$2 \le D < 3$	0.008772	0.004532	1.97	1.97/1.23 = 1.61
$3 \le D < 4$	0.009375	0.005660	1.64	1.64/1.23 = 1.33
$4 \le D < 5$	N/A			
$5 \le D$	0.012500	0.004583	2.73	2.73/1.23 = 2.22

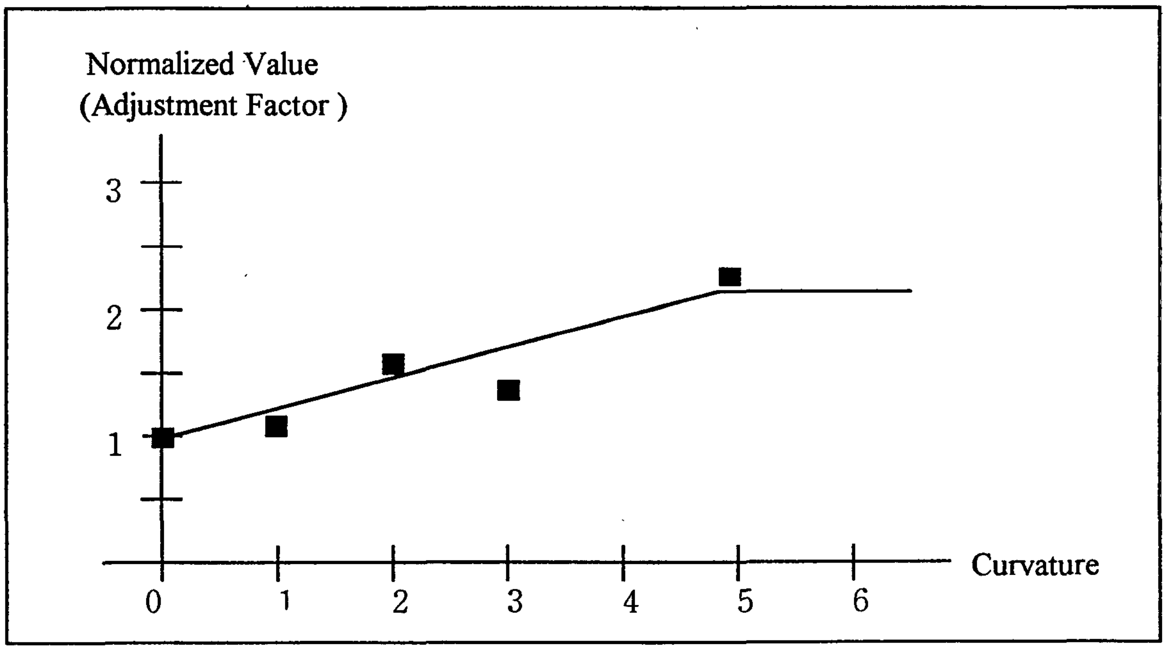


Figure 3.1 Adjustment Factor for Encroachment Rate to Inside of Horizontal Curve

Table 3.3 Comparison of Utility Pole Accident Rate to Outside of Horizontal Curve to Estimation

Horizontal Curvature (deg)	Actual Average # Accidents / Utility Pole / Year (Ea)	Average Expected # Acc (Ex (A_p))	Ea / Ex(A_p)	Normalized Ratio
$0 \leq D < 1$	0.006217	0.005070	1.23	1.23/1.23 = 1.00
$1 \leq D < 2$	0.012931	0.007540	1.72	1.72/1.23 = 1.40
$2 \leq D < 3$	0.009259	0.003941	2.35	2.35/1.23 = 1.92
$3 \leq D < 4$	0.015000	0.006550	2.29	2.29/1.23 = 1.87
$4 \leq D < 5$	0.027174	0.007501	3.62	3.62/1.23 = 2.95
$5 \leq D$	0.021739	0.009247	2.35	2.35/1.23 = 1.92

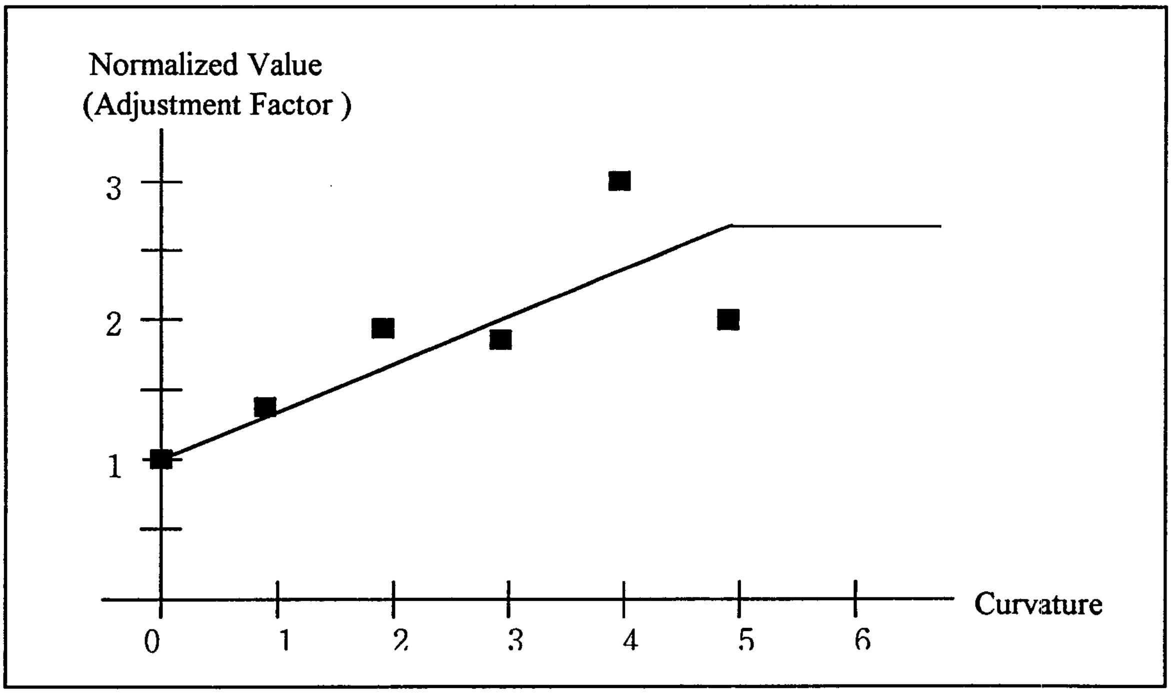


Figure 3.2 Adjustment Factor for Encroachment Rate to Outside of Horizontal Curve

$$A_{curve\text{-}out} = \begin{cases} 0.313\,(D) + 1.0 & D \leq 5.0\text{deg} \quad (R^2 = 0.532) \\ 2.565 & D > 5.0\text{deg} \end{cases} \quad \ldots\ldots \quad \text{Eq. 3.4}$$

where, $A_{curve\text{-}in}$ = adjustment factor for encroachment to inside of curve,
$A_{curve\text{-}out}$ = adjustment factor for encroachment to outside of curve, and
D = degree of curvature (deg).

3-3. Adjustment Factor for Vertical Grade

In order to derive the adjustment factors for vertical grades, the segments were stratified by grade ranges, and the same process was applied as done for horizontal curves. The result is as follows and as shown in Table 3.4 and Figure 3.3.

$$A_{grade} = \begin{cases} 2.845 & G < -5.0\% \\ -0.369\,(G) + 1.0 & 0\% > G \geq -5.0\% \quad (R^2 = 0.657) \\ 0.272\,(G) + 1.0 & 0\% \leq G \leq +5.0\% \quad (R^2 = 0.181) \\ 2.360 & G > +5.0\%. \end{cases} \quad \ldots.. \quad \text{Eq. 3.5}$$

where, A_{grade} = adjustment factor for encroachment rate on grade, and
G = roadway grade (%).

CHAPTER IV. BENEFIT-COST ANALYSIS

IV-1. Estimation of Accident Severity and Cost

The proportions of accident severity could be estimated by accident statistics in Wisconsin. According to the "1992 Wisconsin Traffic Crash Facts" (5) there were 11,177

Table 3.4 Comparison of Utility Pole Accident Rate on Vertical Grade to Estimation

Grade (%)	Actual Average # Accidents / Utility Pole / Year (Ea)	Average Expected # Acc (Ex (A_p))	Ea / Ex(A_p)	Normalized Ratio
-5.5 < G ≤ -4.5	0.009615	0.002746	3.50	3.50/0.96 = 3.64
-4.5 < G ≤ -3.5	0.008929	0.005624	1.59	1.59/0.96 = 1.65
-3.5 < G ≤ -2.5	0.012712	0.007443	1.71	1.71/0.96 = 1.78
-2.5 < G ≤ -1.5	0.008871	0.004703	1.89	1.89/0.96 = 1.96
-1.5 < G ≤ -0.5	0.005757	0.004787	1.20	1.20/0.96 = 1.25
Level	0.004854	0.005045	0.96	0.96/0.96 = 1.00
0.5 ≤ G < 1.5	0.009198	0.005672	1.62	1.62/0.96 = 1.69
1.5 ≤ G < 2.5	0.009748	0.005809	1.68	1.68/0.96 = 1.74
2.5 ≤ G < 3.5	0.006944	0.004666	1.49	1.49/0.96 = 1.55

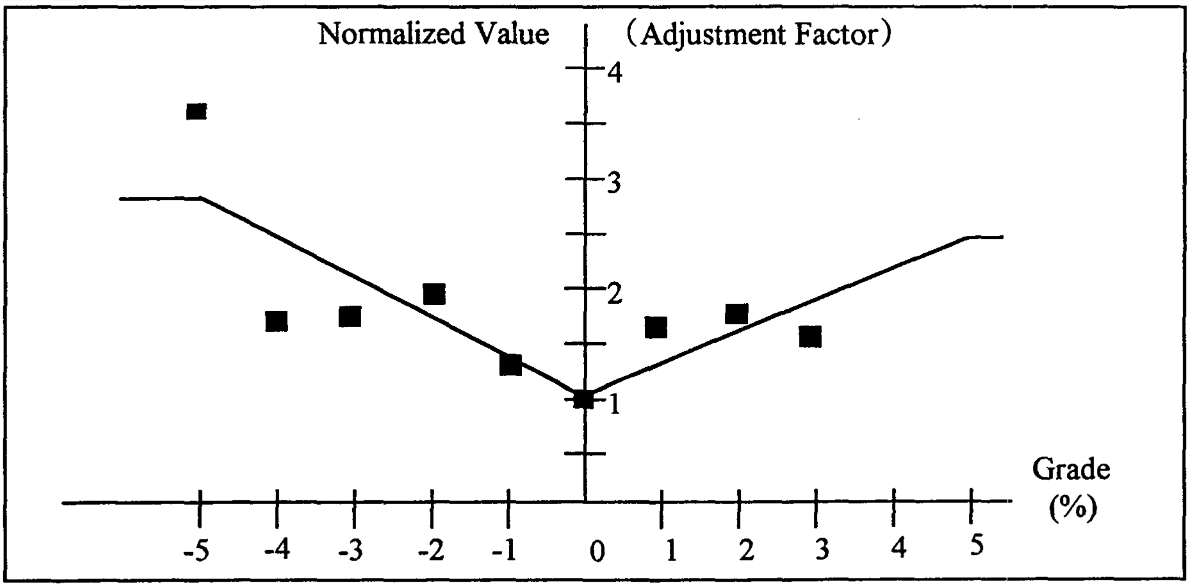


Figure 3.3 Adjustment Factor for Encroachment Rate on Vertical Grade

accidents to fixed objects in rural areas. The fatal, injury, and property damage only crashes were 1.01% (113), 34.00% (3,800), and 64.99% (7,264), respectively.

The FHWA presented their accident cost estimates based on the comprehensive costs in 1994 (6). The comprehensive costs for fatal, injury, and property-damage-only accidents were $2,600,000, $78,333, and $2,000 respectively. These accident cost estimates were used in this study. The weighted average cost for an accident was $54,193, and adjusted to $57,486, the value of 1996

IV-2. Benefit Estimation

The benefit from safety improvement by year is calculated by the equation:

$$ACR = (ANOW - AALT) \times ACOST \quad \text{......................} \qquad \text{Eq. 4.1}$$

where, ACR = expected reduction in accident cost per year,

ANOW = expected number of accidents per year with existing roadside obstacles,

AALT = expected number of accidents per year after improvement, and

ACOST = average cost per accident.

It should be noted that there are the other fixed objects, curves, or side slopes, as well as utility poles on most roadsides. After the safety improvement alternatives are implemented, the net effect from the reduction of utility pole accidents is less than the effect from the estimated utility pole accident reduction. A treatment such as an adjustment factor should be applied to account for this fact (7).

The adjustment is decided by coverage of fixed objects (0 to 100%) which is determined by the dimensions and the numbers of various fixed objects along road. These adjustment factors for roadside object coverage are shown in Table 4.1, 4.2 and 4.3.

Table 4.1 Adjustment Factors When Offset is Increased (f_L)

Coverage	after / before	10ft	15ft	20ft	25ft	30ft
10%	5ft	0.782	0.764	0.745	0.727	0.708
	10ft		0.678	0.672	0.667	0.661
	15ft			0.650	0.650	0.650
	20ft				0.650	0.650
	25ft					0.650
35%	5ft	0.734	0.695	0.655	0.616	0.576
	10ft		0.568	0.548	0.529	0.509
	15ft			0.469	0.469	0.469
	20ft				0.469	0.469
	25ft					0.469
60%	5ft	0.675	0.618	0.560	0.503	0.445
	10ft		0.456	0.423	0.390	0.357
	15ft			0.289	0.289	0.289
	20ft				0.289	0.289
	25ft					0.289

(Source: 9)

Table 4.2 Adjustment Factors When Density is Reduced to 50% (f_M)

Offset / Coverage	10%	35%	60%
5ft	0.611	0.486	0.361
10ft	0.571	0.433	0.295
15ft	0.543	0.392	0.241
20ft	0.521	0.376	0.231
25ft	0.471	0.340	0.210
30ft	0.400	0.289	0.178

(Source: 9)

Table 4.3 Adjustment Factors When is Increased and Density is Reduced to 50% (f_C)

Coverage	after / before	10ft	15ft	20ft	25ft	30ft
10%	5ft	0.904	0.892	0.878	0.855	0.825
	10ft		0.853	0.843	0.824	0.797
	15ft			0.832	0.815	0.790
	20ft				0.815	0.790
	25ft					0.790
35%	5ft	0.886	0.860	0.835	0.797	0.746
	10ft		0.802	0.783	0.751	0.705
	15ft			0.746	0.719	0.681
	20ft				0.719	0.681
	25ft					0.681
60%	5ft	0.861	0.825	0.789	0.737	0.667
	10ft		0.751	0.724	0.677	0.614
	15ft			0.659	0.624	0.573
	20ft				0.624	0.573
	25ft					0.573

VII-3. Cost for Safety Improvement Alternative

The average cost for removing a utility pole was $100, and the installation costs for a new utility pole was $500 for eight-inch (typical and currently used) and $1,800 for 12-inch diameter utility poles. When the density of the utility pole is reduced, a bigger size of utility pole is supposed to be used because of the increased weight of the cable and the structural consideration.

When the lateral offset of utility poles was increased, the utility pole adjustment cost was $600 ($100 + $500) per pole in 1985 dollar, and $726 in 1996 dollars. When the density of utility poles was reduced to 50%, two eight-inch utility poles were removed ($100 x 2) and a 12-inch utility pole was placed ($1,800). Therefore the utility pole adjustment cost was $2,000 per pole in 1985 dollars and $2,420 in 1996 dollars.

VII-4. Benefit-Cost Analysis

The benefit-cost analysis for the safety improvement alternatives was performed by a computer software, "RSUPBC", which was programmed in this study. The program evaluates the cost-effectiveness of each alternative through the project life in terms of benefit-cost ratio and the percentage-reduction of utility pole accidents.

The input data for this program includes the information on the project and general indices such as project life, traffic volume growth rate, discount rate, and consumer price index and index of average hourly earning for the base year. It also contains roadway and roadside conditions which are necessary to predict the utility pole accident rate.

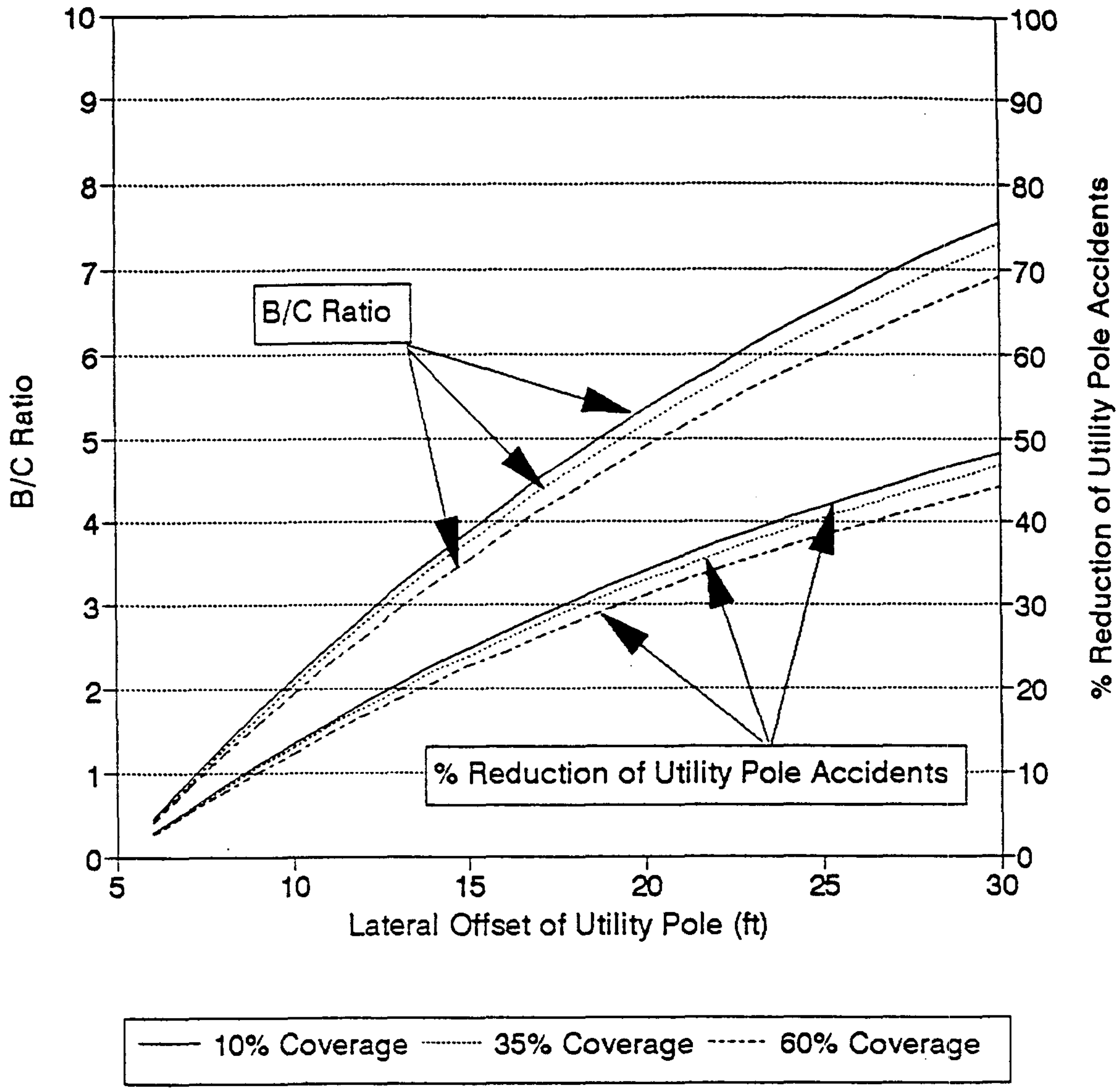
The program "RSUPBC" can provide the benefit-cost ratio and percent of accident reduction by implementation of safety improvement for utility pole accidents on a section. Either or both of the measures of efficiency can be the criteria in the determination for the feasibility of the safety improvement. When the alternative is not fixed, the feasible improvement alternative can be selected by changing the lateral offset of the utility poles by an increment such as one foot. Figure 4.1 is an sample output from the program, and Figure 4.2 is a graph generated with the results from the program in increasing the lateral offset of utility pole by every foot.

CHAPTER VIII. CONCLUSIONS

This study was performed to develop a methodology to provide guidelines for the cost-effective safety improvement of utility pole placement along the highway right-of-way of a rural two-lane highway in Wisconsin. In order to achieve these goals, the utility pole accident rate prediction model was necessary. The basic structure of the utility pole accident rate prediction model in this study was taken from the TRB Special Report 214 (2). This model was also used in the "Roadside Design Guide" from AASHTO (1).

```
< CASE    1 >
============================================================
   ADT =    10000.                  ADT Growth = 1.50 %/year
   Section Length =  1.00 mile
------------------------------------------------------------
   Design Year = 20 year(s)     Discount Rate = 5.0 %/year
------------------------------------------------------------
   CURVATURE (degree) =   .0    GRADE (%) =   .0
============================================================

     UP           Roadside   Lateral    #     Section Total
  Placement         Slope    Offset    UP     # UP Acc/Year
                              (ft)           in Current Year
------------------------------------------------------------
< PREVAILING >

  TANGENT side 1   LEVEL       10.0    18
                                                  .2270

------------------------------------------------------------
< IMPROVED >

  TANGENT side 1   LEVEL       20.0    18
                                                  .1656

  TOTAL COST FOR SAFETY IMPROVEMENT($) =   13068.00
============================================================
   Coverage of                                 Accident
  Roadside Objects                B/C        Reduction(%)
------------------------------------------------------------
          10.0%                   2.51          17.60
          35.0%                   1.81          12.73
          60.0%                   1.12           7.85
============================================================
```

Figure 4.1 Sample Output from "RSUPBC.FOR"



(tangent; level; 5:1 cut slope; 18 poles/mile; ADT=10,000; traffic growth=1.5%/year; discount rate=5%/year; project life=20 years)

Figure 4.2 Benefit-Cost Ratio and Percent Reduction of Utility Pole Accidents by Roadside Coverage to Fixed Objects (hen Lateral Offset of Utility Pole is Increased from 5ft)

This utility pole accident rate prediction model is based on the encroachment model approach, and the utility pole accident rate is determined by the encroachment rate, the probability distribution for lateral extent of encroachment, and the length of potential hazard along the highway. The length of potential hazard can be obtained from the "Hazard Model." The encroachment rate is generally expressed in the form of an exponential function of traffic volume (ADT). However, the encroachment rate is also affected by the horizontal and vertical alignment of the highway. The most commonly used guideline for roadside design, the "Roadside Design Guide", gives some treatment to the encroachment rate by highway alignment. The guide uses the adjustment factors to the encroachment rate by horizontal curvature and downgrade. The roadside encroachment rates vary by area. These adjustment factors were obtained from a limited amount of data and may cause some deficiency in the utility pole accident rate prediction. In addition, as long as the utility pole accident can result from encroachment from the far lane of the highway, the encroachment rate on an upgrade should also be adjusted because the encroachment from the far lane on an upgrade occurs on a downgrade. The probability distribution for lateral extent of encroachment in the current studies in the "Roadside Design Guide" or TRB Special Report 214 were also based on an empirical approach with a limited amount of data, and the distributions were stratified by the mean speed of motor vehicles on the highway. The lateral extent of encroachment is influenced by not only the mean speed of vehicles but also horizontal and vertical alignment, roadside slope under given friction coefficients for roadway and roadside and the lane width.

An analytical method was developed to generate the probability distribution function which included the influencing elements mentioned before. It could be obtained by calculating the minimum lateral extent of encroachment by the combination of the influencing elements and the variation probabilities of encroaching speed and angle. The variations of speed and angle and the probabilities were from the study by McCoy et al. The lateral extent of encroachment was calculated differently by six types of encroachment; near-side and far-side encroachment on a tangent, near-side and far-side encroachment to the inside of a curve, and near-side and far-side encroachment to the outside of a curve.

For the calibration of the encroachment, the data on the roadway and roadside conditions were collected from the datalog and photolog files on the STH012 stored in WisDOT. The utility pole accident records were also obtained from WisDOT.

With the probability distribution function for the lateral extent of encroachment and the utility pole accident data stratified by roadway and roadside conditions, the utility pole accident rate prediction model was calibrated. After calibrating the encroachment rate function on tangent and level segments, the adjustment factors were derived by comparing the actual average utility pole accident rate by each strategy of horizontal curvature or vertical grade with the result from the model calibrated for tangent and level segment of highway.

Roadside encroachment occurs with rare opportunity and a large amount of data should be collected to cover up the variety of roadway condition such as horizontal and vertical alignment, roadside slope, utility pole placement, etc. Therefore it is extremely difficult to collect data on it. The method used in this study could calibrate the encroachment rate with the roadway/roadside condition data and the utility pole accident records. This method did not require any additional effort in data collection for the encroachment rate, and the encroachment rate could be adjusted by strategy.

A benefit-cost analysis was conducted using a program written in this study. The program presents the benefit-cost ratio, and the percent reduction of utility pole accidents by the implementation of the alternative by three levels of roadside coverage with other fixed objects on the roadside. This program can be used for the development of cost-effective safety improvement alternatives against utility pole accidents under a performance level as well as the evaluation of safety improvement alternatives against utility pole accidents.

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