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Selection Of Cost-Effective Countermeasures For Utility Pole Accidents--Users Manual

Research, Development,
and Technology

Turner-Fairbank Highway
Research Center
6300 Georgetown Pike
McLean, Virginia 22101-2296

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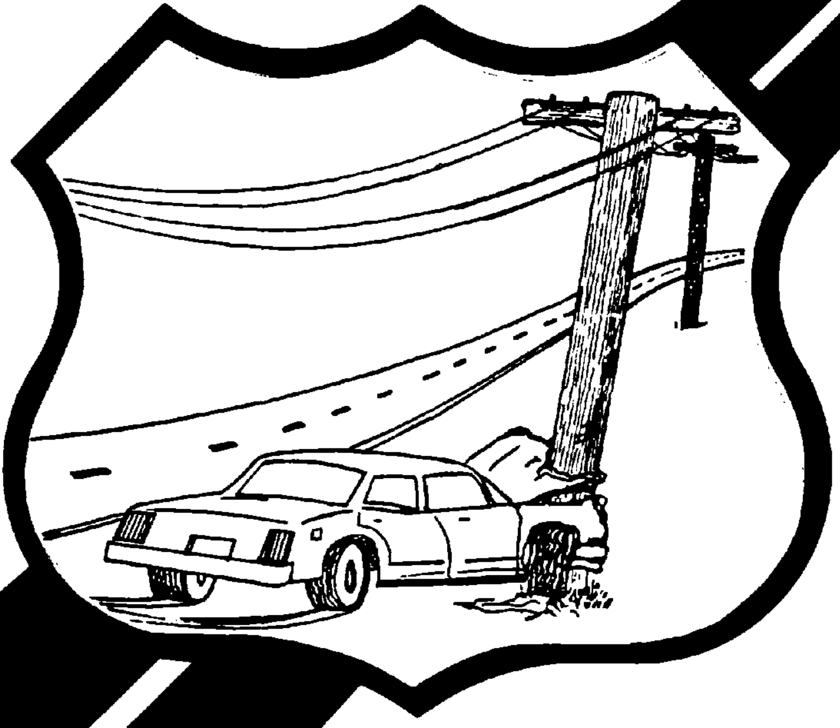

FOREWORD

This user's manual provides guidance for conducting a site specific analysis of roadway sections relative to utility pole accident problems and treatments.

The user's manual contains a procedure which uses tables, graphs and charts to predict traffic accidents involving utility poles. The techniques allow State and local agencies and utility companies to:

- Select the optimal plan for placement of new utility facilities.
- Analyze roadway sections with a utility pole accident problem and select feasible accident countermeasures.
- Analyze alternative countermeasures and select the optimal project.

The economic analysis procedures in both manuals refer to accident cost data developed by the National Safety Council (1981) and the National Highway Traffic Safety Administration (1975). Subsequent research indicates these data significantly underestimate the economic loss per fatality based on current economic theory. These more current estimates, as reported in an article entitled "Accident Costs for Highway safety Decisionmaking" in the June 1986 Public Roads magazine, are $1,156,000 per fatality, $7,100 per injury, and $1,800 per property damage accident, expressed in 1984 dollars.

Copies of the report are available from the National Technical Information Service, 5285 Port Royal Road, Springfield, Virginia, 22161, (703) 487-4690.

For copies of the reports with the programs on microcomputer diskettes contact the Federal Highway Administration's microcomputer support center; the Center for Microcomputers in Transportation, University of Florida, 512 Weil Hall, Gainesville, Florida, 32611, (904) 392-0378.

RJ Betsold
R. J. Betsold, Director
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C. V. Zegeer, M. J. Cynecki

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16. Abstract

This is a user's manual to aid in the selection of cost-effective countermeasures for utility pole accidents.

A manual cost-effectiveness procedure was developed which utilizes graphs, charts, and tables to allow for comparing accident benefits and project costs for such projects as undergrounding utility lines, pole relocation, breakaway poles, and reducing pole density.

The user's manual also contains a discussion of user input variables and methods for establishing project priorities.

A related report on this subject is Utility Pole Accident Countermeasures Evaluation Program and Input Processor: User's Manual (Report No. FHWA-IP-86-14).

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TABLE OF CONTENTS

TABLE OF CONTENTS (Cont'd.)

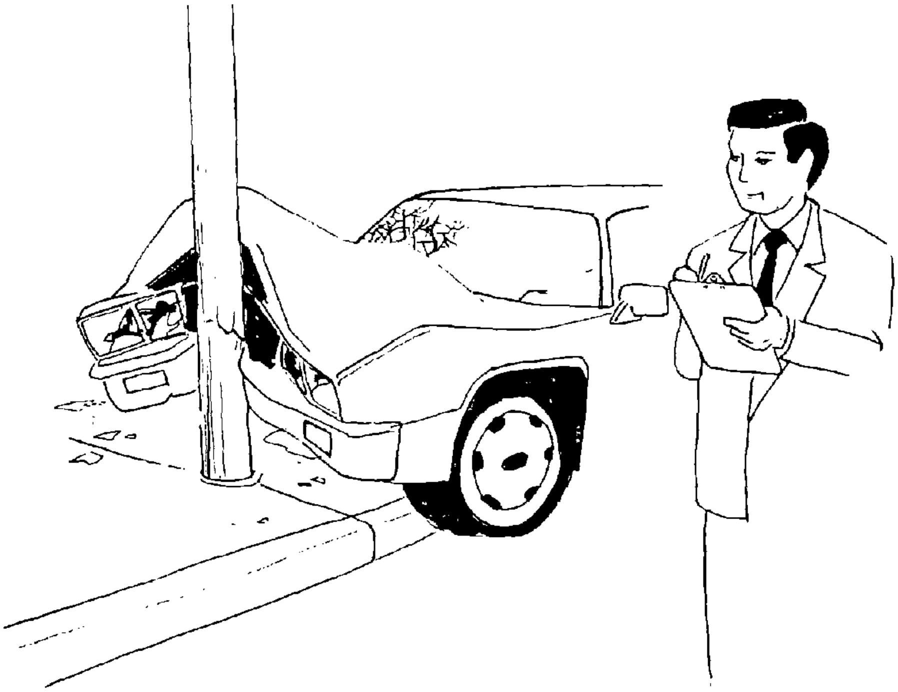
LIST OF FIGURES

LIST OF FIGURES (Cont'd.)

LIST OF TABLES

LIST OF TABLES (Cont'd)

I. INTRODUCTION



Considerable emphasis has recently been given to the development of countermeasures to reduce or eliminate accidents involving fixed objects. Utility poles have been identified as a major roadside hazard. In 1976, Graf et al., [1] estimated that utility pole accidents account for more than 5 percent of the nationwide accidents, more than 5 percent of the nationwide traffic fatalities, and more than 15 percent of the deaths resulting from fixed-object accidents. In 1980, the National Highway Traffic Safety Administration reported that 1,840 of 10,329 fatal fixed-object accidents (17.8 percent) involved a utility pole, which was second only to trees and shrubbery [2]. In a 1976 evaluation of 19,743 single-vehicle, fixed-object accidents, Hall [3] found that one of the major factors associated with this accident type was the lateral placement of roadside obstacles.

In a study by Jones and Baum in 1980 [4], a total of over 8,000 single-vehicle, fixed-object accidents in urban and suburban areas were analyzed, and utility poles were found to be involved in 21.1 percent of the accidents. The authors concluded that in urban areas, approximately 2.2 percent of the total accidents involve impacts with utility poles. Except for rollover accidents, utility pole accidents had the highest rate of injury involvement of all single-vehicle accident types. The density of poles was found to be the single most important factor in predicting utility pole accidents. Roadway and operational factors, including road width, speed limit, and average daily traffic were also related to utility pole accident occurrence [4].

Research has been conducted in recent years to develop and test countermeasures for utility pole accidents. Examples of such countermeasures include the use of breakaway poles, increasing the lateral distance (offset) of the utility poles from the roadway, placement of utility lines underground, multiple use of poles (reducing the number of poles), and installation of guardrail or other protective devices. Modification of the physical roadway may also be useful in reducing utility pole accidents by reducing the probability of vehicles running off the road.

The highway or utility engineer must assess the viability of such alternative countermeasures for each roadway section and decide which approach is best. It becomes necessary to determine the expected benefits and costs which are likely to occur under a variety of traffic and roadway conditions. The purpose of this manual is to provide guidance to Federal, State, and local agencies and to utility companies for selecting the most cost-effective roadway treatment relative to utility pole accidents. The hope is that the use of these procedures will result in an optimal use of limited safety improvement funding with a maximum reduction in related accidents and injuries.

Background

Research has been conducted in recent years to develop and test countermeasures relative to utility pole accidents. This research has involved:

- Crash testing of vehicles with breakaway utility poles.
- Computer simulation of run-off-road accidents.
- Studies relative to the frequency and severity of utility pole accidents.

All three types of research are important to gain a full perspective of problems and to develop possible solutions to utility pole accidents. The latter research, however, is critical to the application of research findings.

A 1983 FHWA study by Zegeer and Parker entitled "Cost-Effectiveness of Countermeasures for Utility Pole Accidents" [5] initiated efforts to apply the research findings in a cost-effectiveness analysis. An in-depth analysis of data was undertaken to determine the effects of implementing multiple pole use, reducing pole frequency, undergrounding of utility lines, and relocating poles. To accomplish this, accident, traffic, and roadway data were collected for over 2,500 miles (4,000 km) of urban and rural roads in 4 States. Using a comparative analysis, lateral pole offset, traffic volume, and pole density were the factors found to be most highly associated with utility pole accidents, and a utility pole accident predictive model was developed [5].

Zegeer and Parker also obtained countermeasure cost data from telephone and utility pole companies throughout the U.S. and performed a cost-effectiveness analysis [5]. Based on the results of that study, general guidelines were developed for selecting cost-effective countermeasures. While those general guidelines are very useful in determining which countermeasures are likely to be cost-effective under certain conditions, a more site-specific procedure is needed. Any given roadway section has its own unique characteristics in terms of utility pole accidents, costs for utility pole-related countermeasures, right-of-way costs, and other factors. In addition, a user may need to use different assumptions for interest rate, project service life, and include the effects of future conditions, such as changes in occupant restraint systems, traffic volumes, and vehicle designs.

Scope and Organization of the User's Guide

This User's Guide was developed to make use of the results of that 1983 FHWA study and provide guidance for conducting a site specific analysis of roadway sections relative to utility pole accident problems and treatments. A cost-effectiveness computer program was developed which considers site-specific factors and possible utility pole treatments. A similar procedure was programmed for use on an IBM-PC microcomputer. A manual cost-effectiveness procedure was also developed using graphs, charts, and tables. The User's Manual also contains a sensitivity analysis of input variables, methods for establishing project priorities, and appendixes which include needed work forms, four sample case studies, and other information. A separate document is also available on program documentation.

The User's Guide is organized into eleven chapters. Chapter I provides an introduction and background to the problem of utility pole accident analysis and the scope and organization of the User's Manual, Chapter II provides a discussion on various utility pole accident countermeasures. Chapter III discusses the inputs necessary to utilize the cost-effectiveness procedures for countermeasure selection and Chapter IV provides guidelines for collecting this data. Various methods of countermeasure selection can be found in Chapters V and VI. Chapter V outlines manual procedure and Chapter VI describes procedures for countermeasure selection using the Utility Pole Accident Countermeasure Evaluation (UPACE) computer program.

The remainder of the User's Guide provides a sensitivity analyses of the various input factors and a discussion of establishing priorities for project implementation (Chapters VII and VIII, respectively). Pertinent references are given in Chapter IX. The Appendixes (Chapter X) provide details on roadside adjustment factors, accident reduction factors, and sample work forms.

II. TREATMENTS FOR UTILITY POLE ACCIDENTS

A variety of different types of roadway treatments have been used or may be appropriate for reducing the frequency or severity of utility pole accidents. These include:

- Locating utility lines underground
- Increasing the lateral offset of poles
- Protective devices
- Reducing the number of poles
- Utilizing breakaway poles
- Other countermeasures

The following is a discussion of each of these treatments.

Locating Utility Lines Underground

This countermeasure involves removing the utility poles and burying the utility lines underground. This will theoretically provide an increase in the recovery area, assuming that a clear roadside and flat sideslopes exist after pole removal. However, in many cases utility pole removal will have little or no effect on the total number of fixed-object accidents, due to the existence of other fixed-objects and/or steep roadside slopes. Therefore, the effectiveness of the countermeasure depends on the feasibility of removing other roadside obstacles in addition to the utility poles.

The determination of the effectiveness of underground lines is a rather complex problem for the reasons discussed above. It should be remembered that even if burying the utility lines results in no reduction in total fixed-object accidents (i.e., all run-off-road vehicles now hit sign posts or trees instead of utility poles), a change in accident severity could result.

The net effect on the overall number of fixed-object accidents is unknown, since it is highly dependent on site-specific roadside characteristics. However, most of the previous researchers seem to agree that burying utility lines will reduce the overall severity of fixed-object accidents (particularly in urban areas), based on the assumption that other, less rigid objects will be hit instead.

Possible problems with underground utility lines include the high installation costs and the fact that many utility poles also carry attached streetlamps. Jones and Baum [4] found that 34 percent of the urban utility poles in their sample had attached streetlamps. Undergrounding of utility lines might necessitate the use of separate luminaire supports (which could be struck by vehicles) or the removal of street lighting on those highway sections.

Increasing the Lateral Offset of Poles

This countermeasure is aimed at reducing utility pole accidents by increasing the distance of the poles from the roadway edge. Mak and Mason [6] found an overrepresentation of pole accidents within 10 feet (3 m) of the roadway which, according to the authors, was due in part to the screening presence of poles which prevent errant vehicles from colliding with more distant obstacles. Fox et al., [7] found poles at the curb to be three times more likely to be struck than those located at 10 feet (3 m) from the curb. Based on these and other research studies, it is apparent that pole relocation further from the roadway will result in a reduction in utility pole accidents. However, one complicating factor is the potential for an increase in other fixed-object accidents after the poles are relocated, since utility poles at close offsets often "screen" an encroaching vehicle from hitting another fixed object.

Protective Devices

This countermeasure involves the use of guardrail or impact attenuating devices around or in front of the utility poles to protect the motorist and lessen the severity of the accident. In terms of the accident severity of striking a utility pole versus guardrail, insufficient information was found which could isolate the severity of each accident type for similar impact speeds, offsets from the road, roadside slope, and roadway alignment. However, evidence from studies by Griffin [8], Glennon [9], and Rinde [10] indicate that the installation of guardrail in front of utility poles may increase the accident severity. Also, installation of guardrails in front of poles will likely increase the frequency of fixed-object accidents, since the guardrail would create a continuous obstacle (instead of a point obstacle) and it must be placed closer to the roadway than the poles.

The use of impact attenuators for utility poles is another possible severity reducing countermeasure. In 1979, Wilson [11] reported on the development and crash testing of a roadside tree/pole crash barrier by the Jet Propulsion Laboratory (JPL) at the California Institute of Technology. The barrier is a configuration of empty aluminum beverage cans contained in a tear-resistant bag encased in a collapsible plywood and steel container. Crash tests have indicated that this device would reduce the severity of the impact to the drivers. Although actual costs were not given for the device, a design goal of $500 per installation was provided. Based on an assessment of various countermeasures, Fox [7] concluded that the installation and use of crash barriers or attenuators would not be effective in urban areas.

Reducing the Number of Poles

Utility pole spacings vary widely based on the type of utility lines. For telephone and small electric lines, pole spacings generally range from 100 to 200 feet (30 to 60 m). For large voltage power lines (more than 69 KV), spacings are commonly 500 feet (150 m) or more, depending on the utility company.

Theoretically, pole spacings of about 30 feet (9 m), representing 176 poles per mile (110 poles/km), would approximate a continuous barrier, since a 4-foot (1.2-m) wide vehicle encroaching at an average angle of about 10-11 degrees could not encroach beyond the poles without striking at least one of them. Although Jones and Baum [4] found pole density was the variable most strongly correlated with utility pole accidents, the precise effect of reducing poles (i.e., increasing pole spacings) has not been quantified.

Countermeasures involving the reduction in the number of poles include:

- Multiple use of poles (i.e., to carry both telephone, electric lines, and luminaires, for example).
- Placing poles on only one side of the street instead of both sides.
- Increasing pole spacings.

One of the practical limitations of these countermeasures listed above is that they may require larger, more rigid poles to provide support for fewer poles or heavier utility lines. This can be costly, and the larger poles could have an adverse effect on utility pole accident severity, which could negate some or all of the possible safety benefits.

Removing or relocating a selected number of poles in particularly hazardous locations is already a common practice among many utility companies, and is recommended particularly after one or more hits have been sustained. This countermeasure requires no formal economic analysis and may be particularly appropriate in rural areas, since utility pole accidents are overrepresented on curves. However, such selective relocation is only applicable for a small percentage of poles, even if such hazardous poles could all be identified and replaced.

Utilizing Breakaway Poles

The use of breakaway poles is a countermeasure directed at reducing utility pole accident severity, not accident frequency. Studies of non-breakaway pole accidents indicate that only about 31 percent of the poles are knocked down or severely damaged upon impact [6]. Since the rapid vehicle deceleration is a major contributing factor to high severity in vehicle-pole accidents, the use of poles designed to break away upon impact is envisioned to be much safer.

The best breakaway pole design is one that will fail due to a shearing stress (such as caused by a vehicular impact) but will retain its bending strength at its base to resist environmental loads [12,13]. Other performance criteria include designs that break away without subjecting vehicle occupants to undue hazard and designs that are economical and cost-effective.

Several designs of breakaway poles have been developed and evaluated. These concepts include:

- The Retrofix concept which involves retrofitting existing poles with a series of saw cuts or drill holes (figure 1).
- The breakaway stub, where an eight foot (2.4-m) section of pole near the base is designed to break away upon impact (figure 2).
- The slipbase hardware design, which can also be utilized with an upper release mechanism to leave the upper portion of the pole or part of the crossarm attached to the wires (figure 3).
- Frangible bases, usually cast aluminum for metal poles that fracture on impact (figure 4).

Of these, the most promising concept is the steel slipbase, based on crash testing.

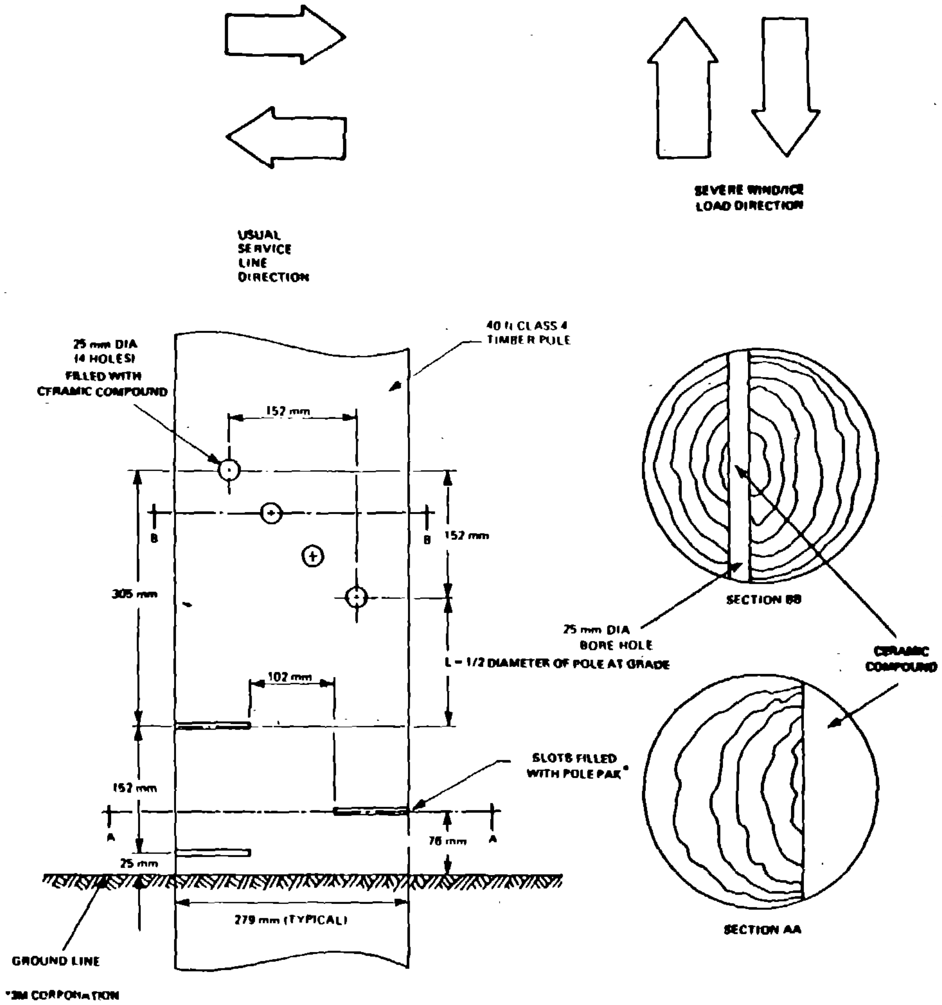


Figure 1. The retrofix concept.

Source: Reference 12

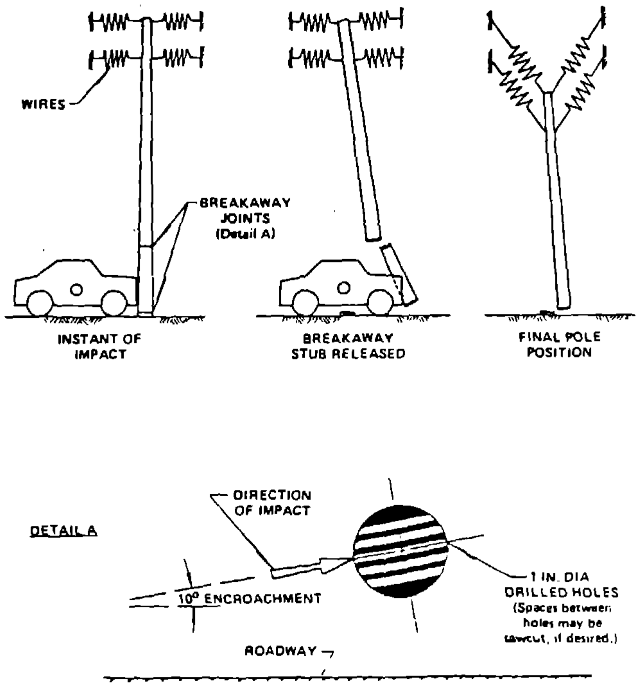


Figure 2. The breakaway stub concept.

Source: Reference 12

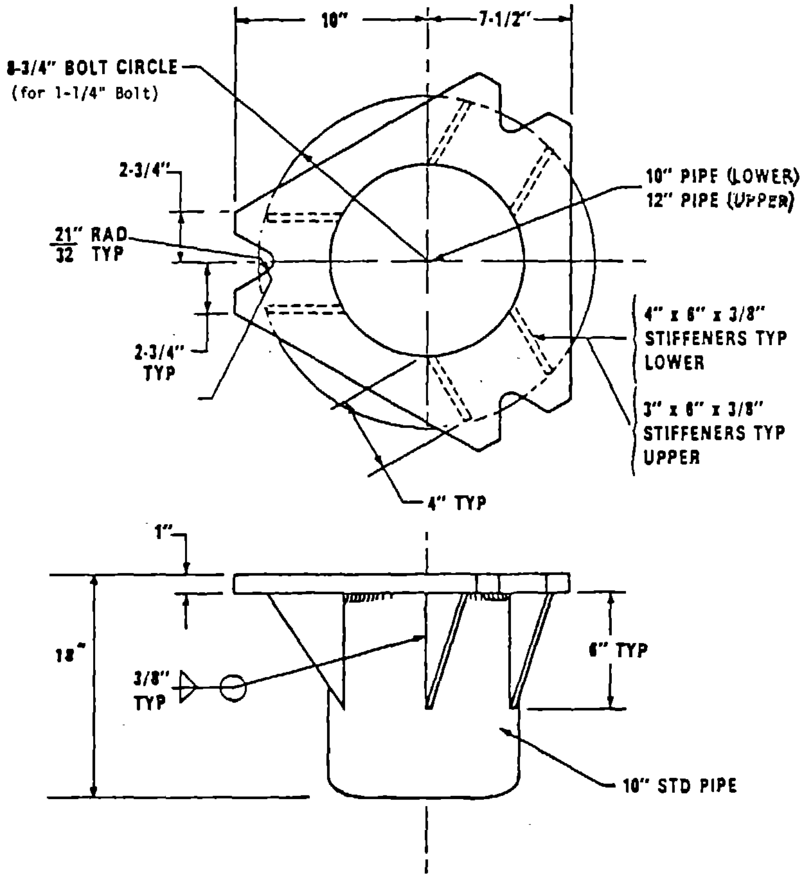


Figure 3. Slip-base hardware design.

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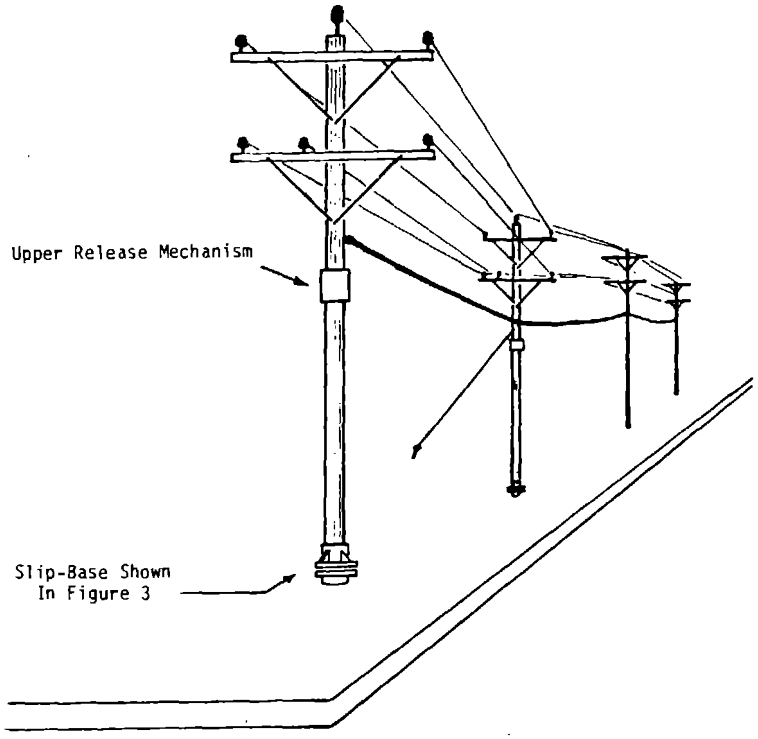


Figure 4. The slip-base concept used with an upper release mechanism.

Source: Reference 12

The use of the breakaway pole has potential as a cost-effective countermeasure, particularly for poles with a high probability of impact. Numerous possible problems still remain with the use of a breakaway pole, such as [6,12,13,14]:

- The weakening of poles could affect the utility lines and possibly cause multiple pole knockdowns.
- The possible added loss of service due to increased chance of pole knockdowns.
- The possible added risk of a vehicle rolling over on a steep side-slope after striking a breakaway pole.
- The non-uniform knockdown potential of some breakaway devices when hit at different angles.
- The need to develop a breakaway pole to resist bending stress due to environmental loads, such as ice and wind loads and loads from transformers, and multiple crossarms.

Of these five potential problems mentioned above, the steel slipbase concept eliminates the problems of multiple pole knockdowns, non-uniform knockdown potential, and weakened bending stress. The increased risk of vehicle rollover is not just a problem with breakaway poles, but may also be a problem with other countermeasures which involve moving the utility poles [12].

The breakaway device is considered as one possible countermeasure for utility pole accidents, although its performance still has to be validated by in-service experience.

Other Countermeasures

Safety programs in general will also directly or indirectly reduce utility pole accident frequency or severity. For example, Jones and Baum [4] suggested that the use of occupant restraints (seat belts and shoulder harnesses) is probably the most cost-effective countermeasure for reducing the utility pole accident severity. Fox et al., [7] recommended pavement resurfacing with a "shellgrip" surface to provide increased skid values and to reduce road surface defects. The authors also recommend that horizontal curves should have a radius exceeding 650 feet (200 m) along with appropriate superelevation.

A review of the literature was conducted by Zegeer and Parker [5] on accident countermeasures which could have an effect on utility pole accidents without moving or otherwise affecting the existing utility poles. These indirect methods include:

- Improved roadway delineation
- Advance warning signs
- Skid resistant pavement overlays
- Widened travel lanes and shoulders
- Increased highway lighting
- Improved roadway alignment through reconstruction.

These countermeasures may logically reduce utility pole accidents by reducing the probability of a vehicle leaving the roadway.

Based on a review of the literature related to these countermeasures, it does not seem likely that any of these treatments are justified based on utility pole accidents alone. Minor accident reductions may occur in utility pole accidents where these countermeasures are implemented. However, these reductions are likely to be quite small, except possibly at a few isolated spots such as horizontal curves where present delineation, warning signs, and/or skid resistance is clearly inadequate, and other roadside hazards do not block the utility poles [5].

Based on the above discussions, the cost-effectiveness analysis in the remainder of this manual deals only with the following five countermeasures:

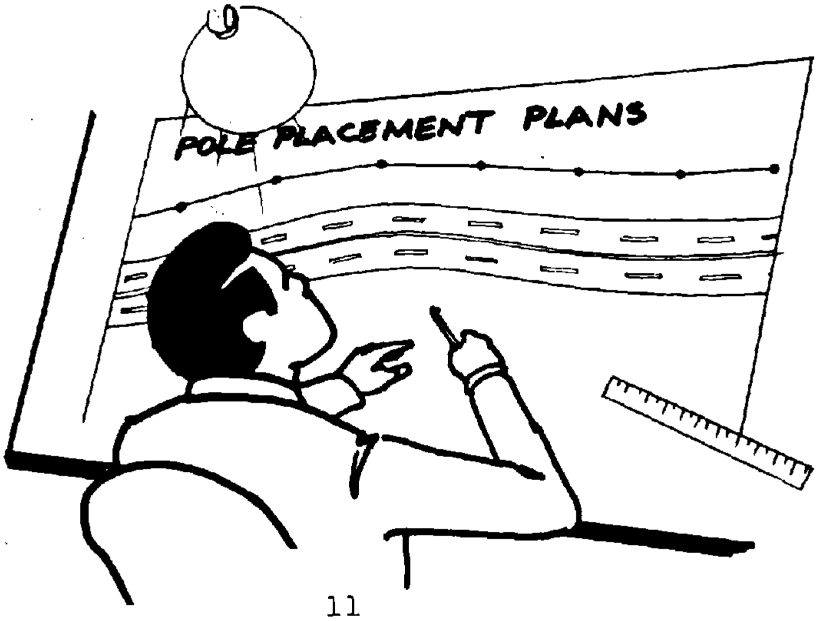
- Undergrounding of utility lines

- Increasing the lateral offset of poles

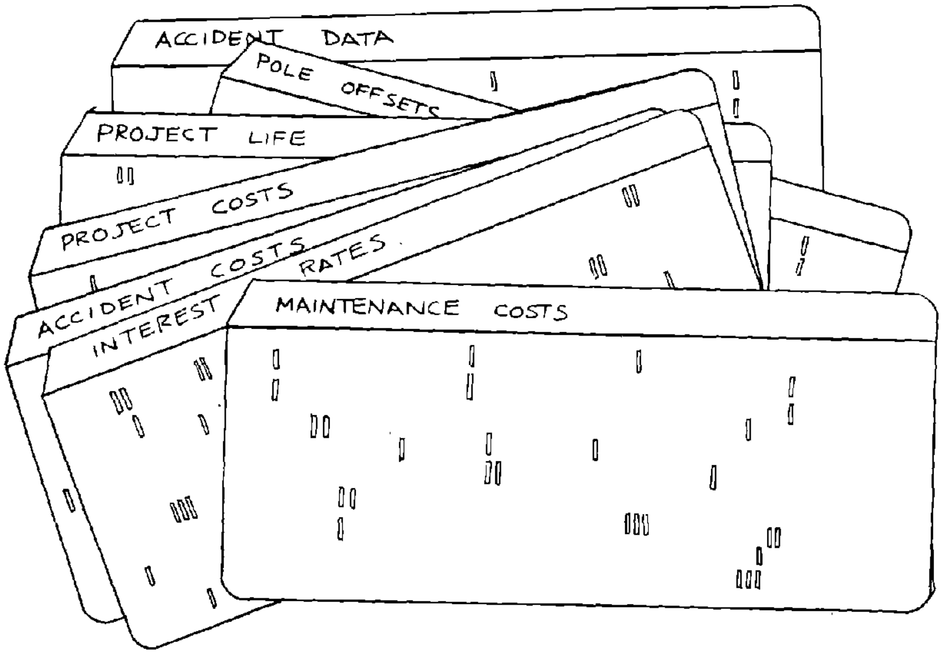
- Reducing the number of poles (multiple pole use, increased pole spacings, and/or placing poles on only one side of the road).

- Utilizing breakaway poles

- Utilizing combinations of increased lateral offset and reduced pole density.



III. PROCEDURE INPUTS AND ASSUMPTIONS



The procedures outlined in this manual are designed to evaluate the cost-effectiveness of utility pole accident countermeasures. The methodology requires that certain information is known or can be assumed for the analysis of each roadway section relative to traffic and roadway conditions, countermeasure effectiveness and costs, economic inputs, and others. Details of each of these inputs are discussed in this chapter for use in the manual and computer procedures.

Basic Assumptions for the Model

When choosing roadway sections for analysis purposes, several points should be remembered:

- The section should have utility poles within about 30 feet (9 m) of the roadway on either one or both sides of the road. For utility poles beyond 30 feet (9 m), the procedures are not valid.
- The section under study must be classified as either urban (including urban fringe or suburban) or rural and either divided or undivided roadways. However, the procedures do not apply to freeways or other facilities with full access control or to sections with utility poles in the median.

- This procedure is not applicable to sections with continuous barriers between the moving vehicles and the utility poles. A continuous barrier may be a steep ditch, a barrier guardrail or parked vehicles along the roadside.

- The methodology is most applicable for roadways with average pole offsets of 2 to 30 feet (0.6 to 9.0 m) on either one or both sides of the roadway. Sections with average pole offsets of less than 2 feet (0.6 m) may be used in the methodology, although less certainty exists in the prediction of utility pole accidents. Thus, for average pole offsets of 0 to 2 feet (0 to 0.6 m), it is recommended that site specific utility pole accident experience be used instead of the predictive model.

- The procedures are valid for roadways with average daily traffic volumes of 500 to 60,000 and for pole densities of 10 to 90 poles per mile (6 to 56 poles/km). For sections outside of these ranges, the analysis may lead to erroneous results.

- The methodologies apply to either wood or metal poles. For a section with concrete poles, the accident frequency relationships should be valid (i.e., similar to wood or metal), although the accident severity is likely to be higher with concrete poles. Thus, if the methodology is applied to a section with concrete poles, the computed benefits from a given countermeasure are likely to be conservative.

Roadway sections chosen for analysis should be relatively homogeneous in terms of traffic volume, pole offset from the roadway, pole spacings, and predominant roadside features (number of lanes, roadside conditions, etc.). If conditions along a section change considerably, the section should be divided, and a separate analysis should be conducted on each section. For example, assume that the average pole offset is about 2 feet (0.6 m) for the first 2 miles (3.2 km) of a 5-mile (8-km) section, and the average pole offset is about 10 feet (3 m) for the next 3-mile (4.8-km) section. In that case, a separate analysis should be conducted for the 2-mile and 3-mile (3.2 and 4.8-km) sections. However, minor fluctuations in traffic volume, pole offset, and other roadway conditions may be tolerated within a section without sacrificing much accuracy.

When sections must be broken up for analysis purposes, section lengths must not be too small. A minimum section length of 0.5 to 1.0 miles (0.8 to 1.6 km) is recommended. Longer sections are preferable up to approximately 10 miles (16 km) as long as roadway conditions are relatively constant, to avoid inaccuracies in matching accidents to the section.

Required Inputs Into the Model

The cost-effectiveness analysis requires that several basic inputs be known or assumed:

- Highway features
- Utility pole features
- Utility pole accident experience
- Estimated utility pole accident experience
- Effectiveness information
- Roadside adjustment factors
- Adjustments for future conditions
- Unit accident costs
- Countermeasure costs
- Other economic factors

The following is a discussion of each of these inputs.

Highway Features

A number of highway features for each roadway section under consideration are used as inputs into the cost-effectiveness procedure. The highway features include:

Route Location - Roadway descriptor.

Route Number or Name - Route descriptor.

Beginning Milepoint - Coded to the nearest tenth of a mile (0.16 km).

Ending Milepoint - Coded to the nearest tenth of a mile (0.16 km).

Section Length - The length of the section in miles measured to the nearest tenth of a mile (0.16 km).

Area Type - A description of the roadside environment. A two-level classification is used to describe area type.

- Urban - The central business district, an outlying business district or suburbanized area. Generally characterized by a moderate to high level of business activity, industrial, commercial or residential land uses, moderate to high pedestrian volumes, curbs and sidewalks, and a moderate to high number of driveways.

- Rural - Low population area characterized by sparse or no land development or farmland along the roadway.

Traffic Volume - The average daily volume of traffic (ADT) in both directions on the facility. This procedure is only applicable for facilities with daily traffic volumes of 500 to 60,000.

Maximum Projected Traffic Volume - The maximum expected daily traffic volume in the design year for the section based on agency planning studies. This value is only used as an input to the computer model when the logrithmic traffic growth model is used.

Traffic Flow - Defined as one-way or two-way. This information is used for display purposes only.

Number of Lanes - The total number of continuous lanes. This value is for display purposes only.

Road Width - Paved width of the road in feet. Curb to curb width for curbed section, total paved width (excluding shoulders) for uncurbed sections. This information is used for display purposes only.

Terrain - A descriptor of the predominant vertical curvature along the roadway. Three levels of terrain are used:

- Flat - level roadway with little or no vertical curvature.
- Rolling - gentle vertical curvature.
- Hilly - high degree of vertical curvature such as in mountainous area.

This information is used for display purposes only.

Road Alignment - The degree of horizontal curvature of the sharpest curve in the roadway segment. The three levels of horizontal curvature are described as:

- Tangent - no horizontal curvature
- Gentle - less than 3° horizontal curvature
- Sharp - greater than 3° horizontal curvature

This information is used for display purposes only.

Speed Limit - The posted speed limit in miles per hour.

Pavement - The type of pavement surface material is described as:

- Concrete.
- Asphalt (bituminuous concrete).

This information is used for display purposes only. This procedure, however, is not applicable to gravel or dirt roads.

Shoulder Type - A description of the shoulder treatment and shoulder width along the roadway. The roadway is either classified as curbed or having a shoulder of a specified width.

Sideslope - The predominant sideslope conditions between the edge of the pavement and the utility poles. The categories of sideslope (defined as the ratio of horizontal to vertical distance) used in this analysis are as follows:

- No Slope - (Flat)
- Fill Slope - 10:1
  6:1
  4:1
  3:1
- Cut Slope - 6:1
  4:1
  3:1
  2:1

A 10:1 slope defines a gentle sideslope and 2:1 is a steep sideslope. A cut section (a positive value) indicates there is an upward slope from the edge of the roadway. A fill section (a negative value) indicates there is a down slope from the edge of the roadway. Figure 5 shows a typical cross section illustrating a cut and fill slope.

Roadside Envelope - The area between the edge of pavement or curb face and 30 feet (9 m) in rural areas or 20 feet (6 m) in urban areas representing the predominate location for fixed-object, run-off-road accidents.

Fixed Object - Rigid fixed objects along the roadway within 30 feet (9 m) of the edge of pavement. Fixed objects can be counted as point or continuous objects. Any object over 10 feet (3 m) in width is classified as a continuous fixed object.

Roadside Coverage Factor (C_F) - An estimate of the coverage of fixed objects within 30 feet (9 m) from the edge of pavement or curb face. The coverage factor is estimated using a 200-foot (60—m) section as shown in table 1. The rules in counting objects are as follows:

1. Two point objects within 10 feet (3 m) of each other are counted as one point object.

2. Continuous objects are represented by their cumulative length along the 200-foot (60-m) section.

3. If an object is screened by another point or continuous object and cannot be struck, it should not be counted.

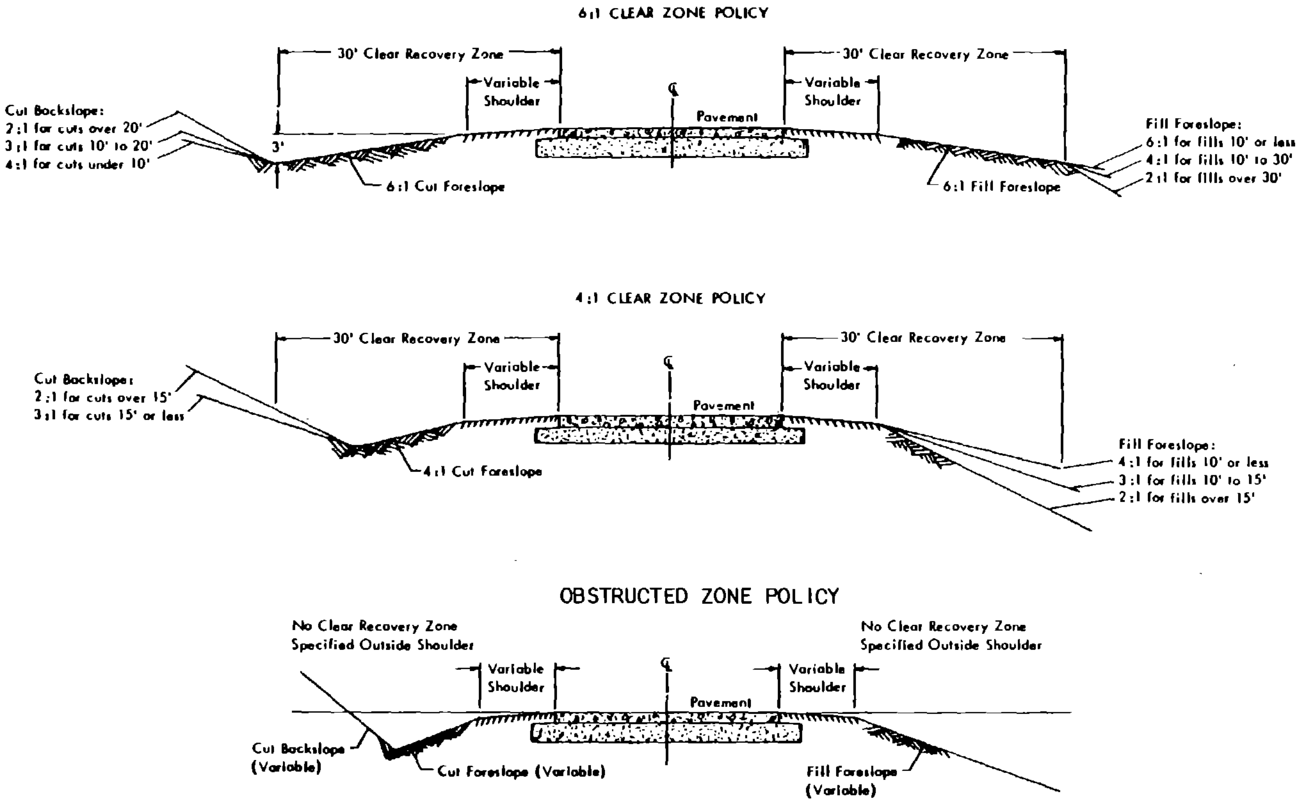


Figure 5. Typical cross-sections for roadside design policies on two-lane highways.

Source: Reference 15

4. When both point and continuous fixed-objects are present the coverage factors are added.

5. The maximum roadside coverage factor is 100 percent.

6. Minor fixed objects which do not usually result in a reported accident when struck are not counted. The guidelines on which object to count and not to count are as follows:

Count	Do Not Count
Most signs (see exceptions at right)	Delineators
Luminaire supports	Small signs on single metal channels
Trees greater than 4 inches (10 cm) diameter	Breakaway signs
Mutliple or massive mailboxes	Small single-post mailboxes
Culvert headwalls	Trees less than 4 inches (10 cm) diameter
Bridge columns and abutments	Brush
Fences	Objects shadowed by guardrail
Rock outcroppings	Utility poles
Rock cuts	
Guardrail	
Concrete barriers	

Table 1. Estimation of fixed-object coverage factor from fixed-object frequency in a 200-foot (60-m) interval.

Number of Point Objects	Total Length of Continuous Objects (Ft.)	Roadside Coverage Factor Percent (C_F)
0	0	0
1	0-10	19
2	11-50	35
3	51-80	50
4	81-100	64
5	101-125	77
6	126-150	89
7 or more	151 or more	100

Note: 1 foot = 0.3 m

Source: Reference 15

For more details, refer to NCHRP Report 247 [15].

Utility Pole Coverage Factor (C_U) - An estimation of the roadside coverage by utility poles. This factor is used as an input to the roadside adjustment process in the computer model, and is calculated using the following table:

Number of Utility Poles Per Mile (1.6 km)		Pole Coverage Factor (C_U)	
Poles on One Side	Poles on Both Sides	Urban	Rural
10	20	0.103	0.065
20	40	0.206	0.130
30	60	0.309	0.195
40	80	0.412	0.260

For further details, refer to Appendix A.

Roadside Hinge Line - The distance from the roadway where the side-slope changes.

Obstructed Zone - The zone of closely spaced fixed objects along the roadway which can be struck by a run-off-road vehicle. An obstructed zone can be in the form of a wall, a dense forest or other group of closely spaced fixed objects. The distance to an obstructed zone is used as an input in calculating the roadside adjustment factor. If a obstructed zone does not exist, the distance to the obstructed zone is assumed to be 30 feet (9 m) in rural areas and 20 feet (6 m) in urban areas.

Roadside Fixed-Objects Line - The weighted average lateral offset of fixed-objects (excluding those objects in the Obstructed Zone) from the roadway. This is assumed to be 12 feet (3.6 m) in rural areas and 7 feet (2.1 m) in urban areas.

Right-of-Way - The total width of land owned by the highway agency for purposes of locating the roadway features including public utilities. This information is used for display purposes only.

Reporting Level Factors (R) - The probability of a reported accident based on the type of object struck. This may also vary by jurisdiction. The model in this procedure assumes the following reporting levels:

Fixed-Object $R_F = 0.90$
Utility Poles $R_U = 0.90$
Curbs $R_K = 0.10$
Obstructed Zone $R_N = 0.50$
Sideslope R_S = Based on degree of slope

Fill Slope	Cut Slope	R_S
10:1	6:1	0.05
6:1	4:1	0.20
4:1	3:1	0.30
3:1	2:1	0.60

A value of 1.0 would indicate that all collisions result in a reported accident.

Utility Pole Features

Several variables related to the utility poles are defined, since they are important inputs into the cost-effectiveness model, as given below:

Utility Pole - A wood, concrete or metal pole supporting electrical or telephone lines which occupy a portion of the highway right-of-way and is the responsibility of utility companies. Only poles within 30 feet (9 m) of the roadway edge are used in the analysis.

Pole Configuration - The location of the line(s) of utility poles with respect to the highway or highway median. Figure 6 illustrates the types of utility pole configurations. This procedure is not applicable to sections with poles in the median.

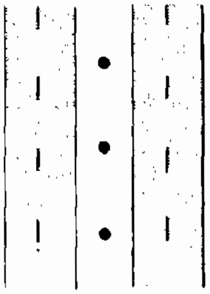
Pole Type - The pole material, classified as wood, metal or concrete.

Pole Diameter - The thickness of the pole near its base, classified as:

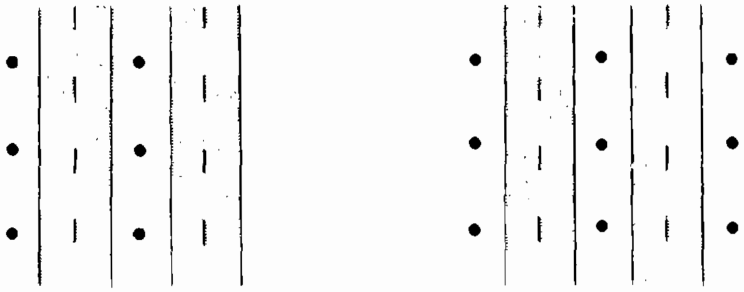
- Small - less then 9 inches in diameter (23 cm)
- Medium - 9-12 inches in diameter (23-30 cm)
- Large - greater than 12 inches in diameter (30 cm)

Partially Obstructed Pole - A pole which is blocked by another rigid fixed object within the encroachment envelope which would prevent a vehicle-pole collision by a run-off-the-road vehicle from at least one point, but would not prevent all vehicle-pole collisions. An example of a partially obstructed pole is shown in figure 7.

Utility pole placement on one side. Utility pole placement on both sides.



Utility pole placement in median.



Utility pole placement
on one side and in median.

Utility pole placement
on both sides and in median.

Figure 6. Possible utility pole configurations.

Source: Reference 5

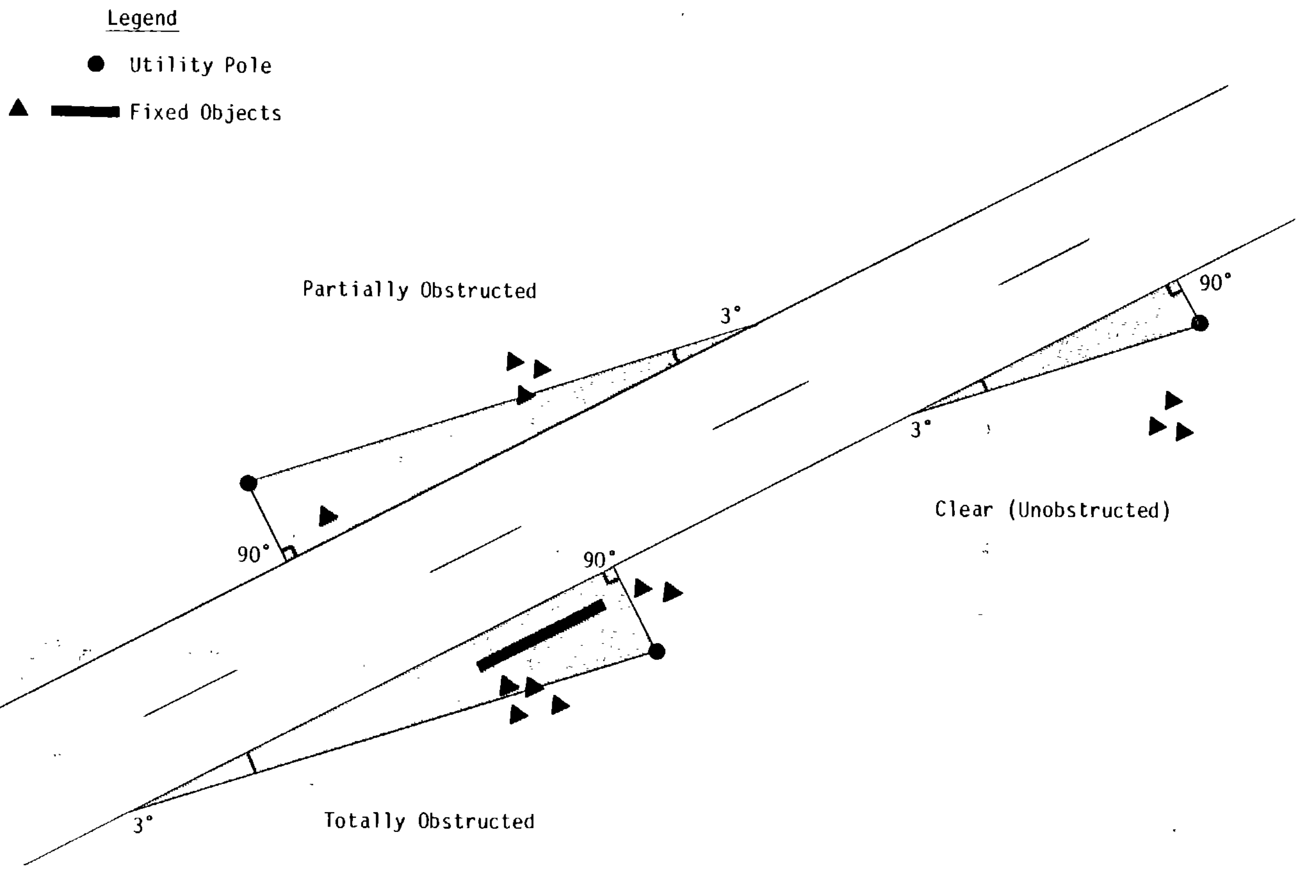


Figure 7. Illustration of clear, partially obstructed and totally obstructed poles based on the positioning of obstacles within the encroachment evelope.

Source: Reference 5

Totally Obstructed Pole - A pole which is blocked by one or more other rigid fixed objects (i.e., a guardrail) within the encroachment envelope that would prohibit a vehicle-pole collision. An example of a totally obstructed pole is shown in figure 7.

Unobstructed Pole - A pole in which no rigid fixed objects exist within the encroachment envelope which would prevent a vehicle-pole collision.

Lateral Pole Offset - The distance measured perpendicularly from the edge of the pavement (or curb face) to the utility pole, to the nearest foot.

Pole Density - The number of utility poles within 30 feet (9 m) from the edge of pavement divided by the section length expressed as poles per mile. Density values are to be calculated using the total number of unobstructed poles on the section.

Average Pole Offset - The mean lateral pole offset in feet defined as:

$$\overline{X} = \frac{\sum_{i=1}^{N} X_i}{N} \qquad (1)$$

Where:

$\overline{X}$ = mean lateral pole offset
X_i = the lateral pole offset for pole i
N = the number of poles on the section

Due to practical considerations, the average pole offset may be calculated based on a measurement of the offset of a representative number of poles on the section and estimate the average offset of the entire section using these measurements.

Utility Line Type - The purpose or type of power line. The type of utility pole line can have a significant impact on countermeasure costs. General utility line categories used in this analysis include:

- Telephone (i.e., communication) lines
- Electric distribution lines, less than 69 KV
- Electric transmission lines, equal to or greater than 69 KV

Utility Pole Accident Experience

Accidents involving a vehicle striking a utility pole must be properly analyzed for use in determining expected benefits (accident savings) which will result from one or more countermeasures. Utility pole accident experience is generally expressed in one of the three units given below:

Utility Pole Accident Frequency (Acc/Mi/Yr) - The number of utility pole accidents per mile per year. The accident frequency is given as follows:

$$\text{Acc/Mi/Yr} = \frac{\text{Acc}}{(L)(T)} \tag{2}$$

Acc/Mi/Yr = Utility pole accidents per mile per year

Acc = Number of utility pole accidents occurring on the section during the analysis period.

T = The analysis time period in years.

L = The section length in miles.

Utility Pole Accident Rate (Acc/HMVM) - Defined as the number of utility pole accidents per hundred million vehicle miles. The accident rate is calculated using the following equation:

$$\text{Acc/HMVM} = \frac{\text{Acc }(100{,}000{,}000)}{(\text{ADT})(365)(T)(L)} \tag{3}$$

Acc/HMVM = Utility pole accidents per 100 million vehicle miles.

Acc = Number of utility pole accidents occurring on the section during the analysis period.

ADT = The average annual daily traffic on the section over the analysis period.

T = The analysis time period in years.

L = The section length in miles.

Utility Pole Accident Rate (Acc/BVPI) - Utility pole accidents per billion vehicle-pole interactions. This is the total number of utility pole accidents expressed as a function of the number of clear (unobstructed) poles times the ADT. This expression is as follows:

$$\text{Acc/BVPI} = \frac{\text{Acc }(1{,}000{,}000{,}000)}{(\text{ADT})(N)(365)(T)} \tag{4}$$

Acc/BVPI = Utility pole accidents per billion vehicle-pole interactions

N = The number of unobstructed poles on the section.

T = The analysis time period in years

For use in the cost-effectiveness model in this manual, the basic units of accidents are the utility pole accident frequency (Acc/Mi/Yr), since Zegeer and Parker found this to be the best measure to use for accident modeling purposes [5]. However, measures of utility pole accident rate may be computed for a section for comparison purposes with other sections.

Estimating Utility Pole Accident Experience

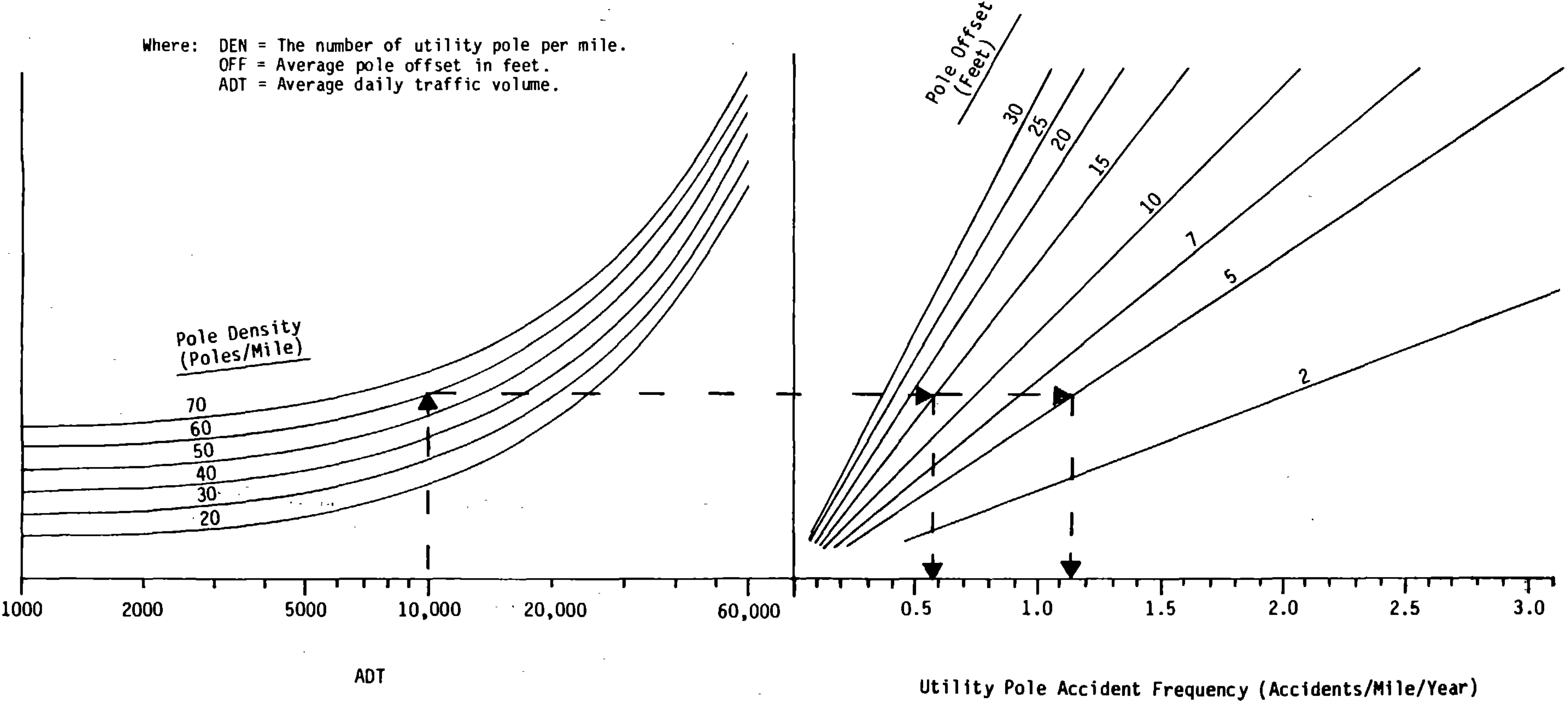
Based on the study by Zegeer and Parker, a model was developed for use in predicting utility pole accidents as a function of daily traffic volume, average pole offset, and pole density. A nomograph can be used to obtain the approximate utility pole accident frequency that would be expected using the model as shown in Figure 8. For example, to estimate the utility pole accidents on a roadway with a daily traffic volume of 10,000, a pole density of 60 poles per mile (37 poles/km) and pole offsets of 5 feet (1.5 m); enter the nomograph at the 10,000 ADT scale, proceed up and turn horizontally at the 60 poles per mile curve (37 poles/km) and cross the 5-foot (1.5 m) offset line. Then proceed down and read 1.14 utility pole accidents per mile per year (0.71 accidents/km/year).

For use in the cost-effectiveness model, the actual utility pole accident experience on a roadway section should be obtained from historic accident files for three or more years. However, for some highway agencies, reliable utility pole accident experience may not be available due to:

- Less than three years of data available.
- High accident reporting threshold (i.e., only injury and fatal accidents are reported).
- The location information of accidents is poor, so accidents cannot be accurately tied to the roadway section of interest.
- The accident report form only designates "fixed-object" accident but does not specify whether a utility pole was struck.
- Utility pole accidents on a section were atypical for the past years due to unusual weather (fog, ice or snow storm) or other random events.

$$ACC/MI/YR = \frac{9.84 \times 10^{-5}\,(ADT) + 0.0354\,(DEN)}{(OFF)^{0.6}} - 0.04 \qquad (5)$$

Where: DEN = The number of utility pole per mile.
OFF = Average pole offset in feet.
ADT = Average daily traffic volume.



Note:

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

Figure 8. Nomograph for predicting utility pole accident frequency.

Source: Reference 5.

In such cases, the actual utility pole accident experience for a site will be inappropriate for use in the cost-effectiveness model. The predictive nomograph can then be used to determine the base accident experience for the section.

Effectiveness Information

Effectiveness information (i.e., accident reduction factors) are needed for use in the cost-effectiveness analysis for the following countermeasures:

- Undergrounding utility lines.
- Increasing the lateral offset of utility poles.
- Reducing the number of poles.
  - Increasing pole spacing
  - Use of poles only on one side of road
  - Multiple use of poles
- Combination of increasing lateral pole offset and reducing pole density.
- Utilizing breakaway poles.

Underground Utility Lines - Placing utility lines underground and removing the poles will eliminate future accidents involving those poles. Thus, the accident reduction factor may be assumed to be approximately 100 percent for utility pole accidents. However, when the poles are removed and no other roadway improvements are made (i.e., removing other fixed obstacles or improving horizontal alignment, etc.), some of the expected reduction in utility pole accidents will be negated by an increase in other fixed-object accidents. This is because some of the encroaching vehicles will hit trees and other objects instead of the utility poles.The net effect of underground lines on fixed-object accidents was determined based on a modification of Glennon's roadside hazard model for NCHRP Report 247 [15], as described later.

It should also be mentioned that underground utility lines require above ground appurtenances such as cabinets for transformers, switching equipment, and sectionalizers. Such facilities must often be placed on the highway right-of-way due to space restrictions or objections from owners of adjoining property.

For those accidents that are merely changed from utility pole accidents to other fixed-object accidents, there is expected to be a reduction in severity for urban areas, but not for rural areas, as documented in previous research studies. Other run-off-road accidents in urban areas are less severe than utility pole accidents, since roadside objects in urban areas typically consist of small sign posts, frangible light poles, small trees, as well as some more rigid objects.

For example, Jones and Baum [4] collected severity data in urban and suburban areas for utility pole accidents and other run-off-road accidents. A summary of accidents where severities were known is shown in table 2.

Table 2. Summary of Run-Off-Road and Utility Pole Accidents.

	Utility Pole Accidents		Run-Off-Road	
Accident Severity	Number	Percent	Number	Percent
Property Damage	664	49.4	2,886	70.2
Injury (A,B, & C)	667	49.7	1,207	29.3
Fatality	12	0.9	19	0.5
Total	1,343	100.0	4,112	100.0

This data indicates that injury and fatal accidents account for 50.6 percent of utility pole accidents, compared to 29.8 percent for other run-off-road accidents. Injury and fatal accidents were grouped together, because of the small sample size of fatal accidents. The severity data in the Jones and Baum study is similar to the severity data involving the analysis of 9,583 utility pole accidents by Zegeer and Parker [5]. For example, fatal accidents were 0.9 percent in the Jones and Baum study and 1.0 percent in the Zegeer study. Injuries occurred in 49.7 percent of utility pole accidents reported by Jones and Baum and 46.3 percent in the Zegeer study. Thus, for estimating purposes, it is assumed that the severity (percent injury and fatal accidents) of other run-off-road accidents would be 30 percent. Therefore, converting utility pole accidents to run-off-road accidents will cause a reduction in injury and fatal accidents from 47.3 percent to 30 percent in urban areas which have speeds of less than 45 mph (72 km/hr). For the cost-effectiveness procedure, the user has the option of selecting an expected accident severity of other run-off-road accidents in urban and rural areas based on the predominant types of roadside obstacles and vehicle operating speeds. No change in severity is expected in rural areas between utility pole accidents and other obstacles, as found from previous research, due to the prevalence of culverts, large trees, bridge piers, and other rigid obstacles in rural areas.

Increasing Lateral Offset of Utility Poles - Relocating poles further from the roadway will generally reduce the frequency of utility pole accidents. The precise relationships between pole offset and accidents was determined by Zegeer and Parker [5], and corresponding accident reduction factors are illustrated in Figure 9 for various pole densities. The accident reduction factor due to relocating utility poles can also be found from the predictive nomograph, as illustrated in Figure 8. For example, assume a 5-foot (1.5-m) average utility pole offset currently exists on a section with a daily traffic volume of 10,000 and 60 poles per mile (38 poles/km). As discussed earlier, this would correspond to 1.14 utility pole accidents per mile per year (0.71 accidents/km/year) using the nomograph. Relocating the poles to 15 feet (4.5 m), with the same traffic volume and pole density would result in a reduction in accident frequency to 0.57 utility

Figure 9. Utility pole accident reduction factors for increasing lateral pole offset.

Pole Offset Before Relocation (Feet)	Expected Percent Reduction in Utility Pole Accidents										
	Pole Offset After Relocation (Feet)										
	6	7	8	9	10	11	12	13	14	15	20-30
4	30	42	49	55	60	63	69	70	72	73	77
5		36	43	50	56	59	65	67	69	70	74
6			27	36	43	48	55	57	60	62	67
7				22	31	37	46	48	52	54	59
8					22	29	39	42	45	48	55
9						18	30	33	37	40	48
10							22	25	30	33	42
11								18	24	27	36
12									11	15	25
13										11	22
14											17

Note: 1 foot = 0.3 m

Source: Reference 5.

pole accidents per mile per year (0.34 accidents/km/year), as illustrated in figure 8.

The accident reduction factor (AR factor) for this pole relocation project would be expressed as the following ratio:

$$\text{AR factor} = \frac{f\ (\text{Before}) - f\ (\text{After})}{f\ (\text{Before})} = \frac{1.14-0.57}{1.14} = 0.50 \qquad (6)$$

Or a 50 percent reduction in accidents is expected. In the same way, accident reduction factors can be determined for other pole relocation projects for a range of traffic volumes and pole densities. A series of accident reduction factor tables was developed based on the predictive model as given in Appendix B. A summary of the number of accidents reduced based on relocating poles is shown in Appendix C.

Based on a review of literature and the analysis of data in this study, there is no conclusive evidence to suggest that pole relocation away from the roadway will significantly affect the severity of utility pole accidents. However, as with other utility pole accident countermeasures, those utility pole accidents converted to other run-off-road fixed-object accidents may have a lower severity in urban areas based on the predominate types of fixed-objects and prevailing vehicle speeds.

Reducing the Number of Poles - The accident reduction factor due to reducing the number of poles by increasing pole spacing or multiple pole use (one line of utility poles in place of two lines of poles) can also be found using the nomograph shown in Figure 8. The accident reduction factor can be determined by entering the nomograph with the two different pole densities and the given traffic volume and pole offset, as discussed for pole relocation. The predictive model was also used to determine relationships between pole density and utility pole accidents.

The shape of the curve for accidents versus pole density differs for pole offsets of less than 20 feet and greater than 20 feet (6.0 m). Thus, more than one accident reduction factor must be used for this countermeasure and accident reduction factors for reducing pole density must be given separately for various ranges of traffic volume and pole offset. A series of accident reduction factor tables for reducing pole density is given in Appendix B for various combinations of traffic volume and pole offset. These accident reduction factors only apply to utility pole accidents and do not account for any increases in other run-off-road accidents which may result. A series of tables showing the number of accidents reduced for pole reduction projects is provided in Appendix C.

Combinations of Increasing Lateral Offset and Reducing Pole Density - Expected accident reduction factors can also be determined from the predictive model for countermeasures involving both increasing lateral pole offset and reducing pole density. Values of traffic volume, pole offset, and pole density during the "before" condition can be input into the model to produce expected utility pole accidents. Then, inputing the appropriate values for the after condition will result in another expected level of accidents. The accident reduction factor can then be computed as the percent difference in utility pole accidents. The accident reduction factor can also be obtained from the nomograph as shown in figure 8 or tables provided in Appendix B. Pole offset was found in an earlier analysis to have no significant effect on accident severity [5]. Thus, it will be assumed that increasing lateral pole offset will not result in any change in accident severity.

Utilizing Breakaway Poles - The effectiveness of breakaway poles was obtained from the literature, since; (1) no vehicle-pole crash testing was conducted as a part of this study; and (2) the lack of past use of breakaway utility poles along roadsides prevented any field accident evaluation of this countermeasure. A review of literature produced some indications of effectiveness data for various types of breakaway poles. For example, Mak and Mason [6] reported that the retrofix breakaway pole might be expected to reduce accident severities to a similar level to those of frangible luminaire supports. However, specific estimates of the changes in accident severity have not been determined for all types of breakaway poles, although work is expected to continue in that area.

For use in the cost-effectiveness model, a range of possible effectiveness levels has been used. The two assumptions are; (1) a conservative assumption of a 30 percent reduction in injury and fatal utility pole accidents; and (2) a less conservative assumption of a 60 percent reduction in injury and fatal utility pole accidents. Based on these hypothetical reductions in injury and fatal accidents after installation of the breakaway poles, a reduction in cost per accident can be computed, as discussed later. No reduction in utility pole accident frequency is expected due to the breakaway device.

It should be stressed that these two values of 30 and 60 percent reduction in injury and fatal accidents were chosen only to illustrate the feasibility of breakaway poles under two hypothetical levels of effectiveness. No judgments can accurately be made on the cost-effectiveness of breakaway utility poles until more conclusive data are available. A summary is given in table 3 showing effectiveness information for each countermeasure which will be used in the cost-effectiveness analysis.

Roadside Adjustment Factor

Roadside conditions vary widely in terms of fixed-objects, shoulder width, curbs, and sideslopes. Therefore, when applying a countermeasure to a site the net reduction in roadside accidents will be less than the reduction in utility pole accidents. For example, when utility poles are removed, the out-of-control vehicles that would have had a reported utility pole accident may instead have: (1) no collision at all (the

Table 3. Summary of effectiveness information to be used in the cost-effectiveness model.

Countermeasure	Effect on Utility Pole Accident Frequency	Effect on Utility Pole Accident Severity
1. Increase Lateral Pole Offset	Causes a reduction in utility pole accidents as computed from predictive model. Some increase in other run-off-road accidents may occur (as computed from roadside hazard model).	Assumed to have no effect on utility pole accident severity. However, a reduction in overall severity from 47.3% to 30.0% (I+F) may be expected in urban areas for the utility pole accidents converted to run-off-road accidents due to lower severity of ROR accidents.
2. Underground Utility Lines	Eliminates utility pole accidents, but may cause an increase in other run-off-road accidents (as computed from roadside hazard model).	Reduces average percent of injury and fatal accidents of these accidents converted to run-off-road from 47.3% to 30.0% in urban areas.
3. Reduce Pole Density (Multiple Pole Use)	Causes a reduction in utility pole accidents, as computed from the predictive model. Some increase in other run-off-road accidents may occur (as computed from the roadside hazard model).	Assumed to have no effect on utility pole accidents severity. However, a reduction in overall severity from 47.3% to 30.0% (I+F) may be expected in urban areas for the utility pole accidents converted to run-off-road accidents due to lower severity of ROR accidents.
4. Combinations of Increase Lateral Pole Offset and Reduce Pole Density	Causes a reduction in utility pole accidents, as computed from the predictive model. Some increase in other run-off-road accidents may occur (as computed from the roadside hazard model).	Assumed to have no effect on utility pole accidents severity. However, a reduction in overall severity from 47.3% to 30.0% (I+F) may be expected in urban areas for the utility pole accidents converted to run-off-road accidents due to lower severity of ROR accidents.
5. Breakaway Pole Feature	Assumed to have no effect.	Effect on severity has not been properly quantified in prior research, since new breakaway devices are being developed and tested. The expected percent reduction in injury and fatal accidents is selected by the user.

Source: Reference 5.

vehicle may recover); (2) hit some other fixed object; or (3) roll over down the sideslope.

The increases in other run-off-road accidents due to utility pole accident countermeasures is dependent on the roadside characteristics. Work was conducted by Glennon in previous studies for NCHRP, which involved the development of a roadside hazard model for comparison of roadside improvements [15]. In a later study on roadside accidents for various roadside clear zones, Glennon found that the model over-predicts the roadside hazard by a factor of from 2 to 8, depending on the magnitude of road sideslopes and the coverage of fixed objects. The model was refined to more accurately predict general roadside hazard. In a later study [5] additional modifications were made to the roadside hazard model to allow for predicting the net effectiveness of utility pole accident countermeasures.

The roadside adjustment factor developed for this procedure is quite complex and involves computing the probability of run-off-road accidents and utility pole accidents before and after a countermeasure. However, the model is not dependent on encroachment rates. Combinations of 16 equations are the basis of the calculations, depending on the specific roadside conditions. For example, assume a line of utility poles at 5-foot (1.5-m) lateral offset and a dense row of trees at a 6-foot (1.8-m) offset behind the poles. The roadside adjustment for moving only the utility poles back to 30 feet (9 m) would be nearly zero, since virtually all of the reduction in utility pole accidents would be negated by an increase in vehicle-tree accidents. A similar pole relocation project on a totally clear roadside with a 10:1 sideslope would result in a roadside adjustment of nearly 1.0. This implies that virtually all of the reduction in utility pole accidents would be a net reduction in run-off-road accidents.

The roadside adjustment factor is multiplied by the computed reduction in utility pole accidents. Assume that a reduction of 10 utility pole accidents per year are expected due to undergrounding a utility line on a roadway section. Due to trees and other objects along the road, the roadside adjustment factor is 0.60. Thus, the net reduction in roadside accidents is 10 x 0.6 = 6 accidents per year. The UPACE computer program is able to compute roadside adjustment factors for various combinations of roadside characteristics and utility pole treatments. The inputs into the roadside adjustment model include:

- Coverage of fixed objects along the road (0 to 100 percent).
- Lateral offset of fixed objects, 0 to 30 feet (0 to 9 m) in rural areas, 0 to 20 feet (0 to 6 m) in urban areas.
- Spacing and lateral offset of utility poles before and after the countermeasure implementation.

- The distribution of lateral displacement of encroaching vehicles (values based on previous studies).

- The offset of the break in slope (rural areas) or existence of a curb (urban areas).

- The general order of obstacles from the edge of roadway.

- The assumed percent of reported run-off-road accidents.

Example summary tables are given of roadside adjustment factors for undergrounding (table 4), increasing lateral pole offsets, (table 5), and reducing pole density through increasing pole spacing or multiple pole use (table 6), and a combination of reducing pole density and increasing pole offset (table 7). These tables can be used for determining the roadside adjustment factor when utilizing the manual cost-effectiveness procedure.

To simplify the roadside adjustment factor for use in the manual procedure, several basic assumptions were made, including the following:

- Rural areas have sideslopes of 6:1 and 4:1.

- Where fixed objects exist in rural areas, they are generally scattered within 30 feet (9 m) of the roadway, and their average offset is 12 feet (3.6 m).

- Sections in urban areas are curbed, and fixed objects are scattered within 20 feet (6 m) of the roadway, and their average offset is 7 feet (2.1 m).

Other assumptions for the roadside adjustment factors are discussed in Appendix A.

To utilize the adjustment factor in this study, the percent coverage of fixed objects must be known for a given roadway section. In their study on clear recovery zones, Graham and Harwood [15] have developed guidelines for determining coverage factors. Their procedure involves counting rigid fixed objects in 200-foot (60-m) increments along the roadway back to specified increments of lateral offset. A list of the types of fixed objects to be counted (and not counted) is given in the discussion of the roadside coverage factor, presented earlier in this chapter. Then, the coverage factor in percent is determined from Table 1 based on the number of point objects within the 200-foot (60-m) roadway segment. Thus, any length of roadway section can be analyzed in terms of the average percent coverage factor for the 200-foot (60-m) segments in the section.

Considering a 2,000-foot (600-m) roadway section with an average of 2 point objects per 200-foot (60-m) increment, corresponds to a 35 percent coverage factor of fixed objects. When counting fixed objects for determination of the roadside adjustment factor, only count those objects within 20 feet (6 m) of the roadway in urban areas and 30 feet (9 m) in rural areas.

Table 4. Roadside adjustment factors (H_R) for undergrounding utility lines.

Pole Offset (Feet)	Rural Areas							Urban Areas						
	Roadside Coverage Factor (C_F)							Roadside Coverage Factor (C_F)						
	10%	20%	30%	40%	50%	60%	80%	10%	20%	30%	40%	50%	60%	80%
2	0.62	0.57	0.52	0.47	0.42	0.37	0.28	0.71	0.65	0.60	0.55	0.50	0.44	0.34
5	0.61	0.56	0.51	0.46	0.41	0.36	0.26	0.67	0.61	0.54	0.48	0.42	0.36	0.23
7	0.60	0.55	0.50	0.45	0.40	0.35	0.25	0.64	0.57	0.50	0.43	0.36	0.29	0.14
10	0.57	0.52	0.46	0.41	0.35	0.30	0.19	0.61	0.54	0.48	0.41	0.34	0.27	0.14
15	0.54	0.48	0.42	0.36	0.30	0.24	0.12	0.53	0.47	0.41	0.35	0.29	0.24	0.12
20	0.52	0.46	0.41	0.35	0.29	0.23	0.12	0.40	0.36	0.31	0.27	0.22	0.18	0.09
25	0.47	0.42	0.37	0.31	0.26	0.21	0.11							
30	0.40	0.36	0.31	0.27	0.22	0.18	0.09							

Note: 1 foot = 0.3 m

Table 5. Roadside adjustment factors (H_R) for increasing lateral pole offset.

Pole Offset (Feet)		Area Type Rural or Urban	Roadside Coverage Factor (C_F)						
Before Improvement	After Improvement		10%	20%	30%	40%	50%	60%	80%
2	15	R	0.81	0.79	0.77	0.75	0.73	0.71	0.67
	20	R	0.76	0.73	0.69	0.65	0.62	0.58	0.51
	25	R	0.73	0.68	0.64	0.59	0.55	0.50	0.41
	30	R	0.72	0.67	0.61	0.56	0.51	0.46	0.36
5	15	R	0.80	0.77	0.75	0.73	0.71	0.69	0.64
	20	R	0.75	0.71	0.67	0.64	0.60	0.56	0.48
	25	R	0.72	0.67	0.62	0.58	0.53	0.48	0.38
	30	R	0.71	0.66	0.60	0.55	0.50	0.45	0.34
7	15	R	0.78	0.76	0.73	0.71	0.68	0.66	0.61
	20	R	0.74	0.70	0.66	0.62	0.58	0.54	0.46
	25	R	0.71	0.66	0.61	0.56	0.51	0.46	0.36
	30	R	0.70	0.64	0.59	0.54	0.48	0.43	0.32
10	20	R	0.67	0.62	0.57	0.52	0.47	0.42	0.32
	25	R	0.66	0.61	0.55	0.49	0.43	0.38	0.26
	30	R	0.66	0.60	0.54	0.48	0.42	0.36	0.24
15	20	R	0.65	0.58	0.51	0.43	0.36	0.29	0.14
	25	R	0.65	0.58	0.51	0.43	0.36	0.29	0.14
	30	R	0.65	0.58	0.51	0.43	0.36	0.29	0.14
20	30	R	0.65	0.58	0.51	0.43	0.36	0.29	0.14
2	10	U	0.86	0.83	0.81	0.78	0.75	0.72	0.67
	15	U	0.84	0.79	0.75	0.70	0.65	0.60	0.51
	20	U	0.83	0.78	0.72	0.67	0.61	0.55	0.44
5	10	U	0.84	0.79	0.74	0.69	0.64	0.60	0.50
	15	U	0.82	0.75	0.69	0.62	0.55	0.49	0.35
	20	U	0.82	0.74	0.67	0.60	0.52	0.45	0.31
7	15	U	0.80	0.71	0.62	0.53	0.44	0.36	0.18
	20	U	0.80	0.71	0.62	0.53	0.44	0.36	0.18
10	15	U	0.80	0.71	0.62	0.53	0.44	0.36	0.18
	20	U	0.80	0.71	0.62	0.53	0.44	0.36	0.18
15	20	U	0.80	0.71	0.62	0.53	0.44	0.36	0.18

Note: 1 foot = 0.3 m

Table 6. Roadside adjustment factors (H_R) for reducing pole density or multiple pole use.

Pole Offset (Feet)	Rural Areas							Urban Areas						
	Roadside Coverage Factor (C_F)							Roadside Coverage Factor (C_F)						
	10%	20%	30%	40%	50%	60%	80%	10%	20%	30%	40%	50%	60%	80%
2	0.62	0.57	0.52	0.47	0.42	0.37	0.28	0.71	0.65	0.60	0.55	0.50	0.44	0.34
5	0.61	0.56	0.51	0.46	0.41	0.36	0.26	0.67	0.61	0.54	0.48	0.42	0.36	0.23
7	0.60	0.55	0.50	0.45	0.40	0.35	0.25	0.64	0.57	0.50	0.43	0.36	0.29	0.14
10	0.57	0.52	0.46	0.41	0.35	0.30	0.19	0.61	0.54	0.48	0.41	0.34	0.27	0.14
15	0.54	0.48	0.42	0.36	0.30	0.24	0.12	0.53	0.47	0.41	0.35	0.29	0.24	0.12
20	0.52	0.46	0.41	0.35	0.29	0.23	0.12	0.40	0.36	0.31	0.27	0.22	0.18	0.09
25	0.47	0.42	0.37	0.31	0.26	0.21	0.11							
30	0.40	0.36	0.31	0.27	0.22	0.18	0.09							

Note: 1 foot = 0.3 m

Table 7. Roadside adjustment factors (H_R) for a combination of increasing pole offset and reducing pole density.

Reduce Pole Density by 20 Percent									
Pole Offset (Feet)		Area Type Rural or Urban	Roadside Coverage Factor (C_F)						
Before Improvement	After Improvement		10%	20%	30%	40%	50%	60%	80%
2	15	R	0.72	0.69	0.65	0.62	0.59	0.55	0.48
	20	R	0.71	0.67	0.63	0.59	0.54	0.50	0.42
	25	R	0.70	0.65	0.60	0.56	0.51	0.46	0.37
	30	R	0.69	0.64	0.59	0.54	0.49	0.44	0.38
5	15	R	0.71	0.67	0.64	0.60	0.57	0.53	0.46
	20	R	0.70	0.65	0.61	0.57	0.53	0.48	0.40
	25	R	0.69	0.64	0.60	0.54	0.49	0.44	0.35
	30	R	0.68	0.63	0.58	0.53	0.48	0.42	0.32
7	15	R	0.69	0.66	0.62	0.58	0.54	0.51	0.43
	20	R	0.68	0.64	0.60	0.55	0.51	0.46	0.37
	25	R	0.68	0.63	0.58	0.53	0.48	0.43	0.32
	30	R	0.67	0.62	0.57	0.51	0.46	0.41	0.30
10	20	R	0.63	0.58	0.53	0.47	0.42	0.37	0.26
	25	R	0.63	0.58	0.52	0.46	0.41	0.35	0.24
	30	R	0.64	0.58	0.52	0.46	0.40	0.34	0.22
15	20	R	0.59	0.52	0.46	0.39	0.33	0.26	0.13
	25	R	0.61	0.54	0.47	0.41	0.34	0.27	0.14
	30	R	0.62	0.55	0.48	0.41	0.34	0.27	0.14
20	30	R	0.61	0.54	0.47	0.40	0.34	0.27	0.14
2	10	U	0.80	0.76	0.72	0.69	0.65	0.61	0.54
	15	U	0.80	0.75	0.70	0.65	0.60	0.55	0.45
	20	U	0.80	0.74	0.69	0.63	0.58	0.52	0.41
5	10	U	0.76	0.70	0.65	0.59	0.53	0.48	0.37
	15	U	0.77	0.70	0.64	0.57	0.51	0.44	0.31
	20	U	0.78	0.71	0.64	0.57	0.50	0.43	0.29
7	15	U	0.74	0.66	0.58	0.49	0.41	0.33	0.16
	20	U	0.75	0.67	0.59	0.50	0.42	0.34	0.17
10	15	U	0.71	0.63	0.56	0.48	0.40	0.32	0.16
	20	U	0.74	0.66	0.58	0.49	0.41	0.33	0.16
15	20	U	0.68	0.61	0.53	0.46	0.38	0.30	0.15

Note: 1 foot = 0.3 m

Table 7. Roadside adjustment factors (H_R) for a combination of increasing pole offset and reducing pole density (Continued).

Reduce Pole Density by 50 Percent									
Pole Offset (Feet)		Area Type Rural or Urban	Roadside Coverage Factor (C_F)						
Before Improvement	After Improvement		10%	20%	30%	40%	50%	60%	80%
2	15	R	0.66	0.62	0.58	0.53	0.49	0.45	0.36
	20	R	0.66	0.62	0.57	0.53	0.48	0.44	0.34
	25	R	0.66	0.61	0.56	0.52	0.47	0.42	0.32
	30	R	0.66	0.61	0.56	0.51	0.46	0.41	0.31
5	15	R	0.65	0.61	0.56	0.52	0.47	0.43	0.34
	20	R	0.65	0.60	0.56	0.51	0.46	0.42	0.33
	25	R	0.65	0.60	0.55	0.50	0.45	0.40	0.31
	30	R	0.65	0.60	0.55	0.50	0.45	0.40	0.29
7	15	R	0.64	0.59	0.55	0.50	0.46	0.41	0.32
	20	R	0.64	0.59	0.54	0.50	0.45	0.40	0.30
	25	R	0.64	0.59	0.54	0.49	0.44	0.39	0.29
	30	R	0.64	0.59	0.54	0.49	0.43	0.38	0.28
10	20	R	0.60	0.54	0.49	0.44	0.38	0.33	0.22
	25	R	0.60	0.55	0.49	0.44	0.38	0.32	0.21
	30	R	0.61	0.55	0.49	0.44	0.38	0.32	0.21
15	20	R	0.56	0.50	0.43	0.37	0.31	0.25	0.12
	25	R	0.57	0.51	0.45	0.38	0.32	0.26	0.13
	30	R	0.58	0.52	0.45	0.39	0.32	0.26	0.13
20	30	R	0.56	0.50	0.44	0.38	0.31	0.25	0.13
2	10	U	0.75	0.70	0.66	0.61	0.57	0.52	0.43
	15	U	0.76	0.70	0.65	0.60	0.55	0.50	0.40
	20	U	0.76	0.70	0.65	0.60	0.54	0.49	0.38
5	10	U	0.71	0.65	0.59	0.53	0.47	0.41	0.29
	15	U	0.72	0.66	0.59	0.53	0.46	0.40	0.27
	20	U	0.73	0.66	0.59	0.53	0.46	0.39	0.26
7	15	U	0.69	0.61	0.54	0.46	0.38	0.31	0.15
	20	U	0.70	0.62	0.55	0.47	0.39	0.31	0.16
10	15	U	0.65	0.58	0.51	0.44	0.36	0.29	0.15
	20	U	0.68	0.60	0.53	0.45	0.38	0.30	0.15
15	20	U	0.60	0.53	0.46	0.40	0.33	0.27	0.13

Note: 1 foot = 0.3 m

The roadside adjustment factor (H_R) must always be between the values of 0 and 1. Since these adjustment factors are multiplied by the expected reduction in utility pole accidents, a low adjustment factor (i.e., 0.10) implies that most of the reduction in utility pole accidents are negated by a corresponding increase in other roadside object accidents. Thus, the countermeasures which are most effective in reducing utility pole accidents (i.e., undergrounding of lines) will result in the greatest increase in accidents corresponding to other fixed-objects, since encroaching vehicles will then hit other objects instead of utility poles.

Note that the roadside adjustment factors are lower for underground utility lines (table 4) compared to increasing pole offset (table 5) under similar situations. For example, assume pole offsets of 5 feet (1.5 m) with a 60 percent coverage of fixed objects on a rural road. The roadside adjustment factor for lines underground is 0.36 (table 4), compared to a value of 0.45 (table 5) for relocating poles to 30 feet (9 m). This implies that the percent increase in other fixed objected accidents are slightly higher for lines underground than for pole relocation, even though lines underground would reduce more utility pole accidents that would be gained from pole relocation.

Adjustments for Future Conditions

Any major change in occupant restraint system usage, the use of passive restraints (automatic safety belts or air bags) and/or automobile size could have an effect on the average severity of utility pole accidents. The computer model allows the user to account for future occupant restraint usage and automobile downsizing by applying adjustments to the average severity of utility pole accidents for various years. This adjustment is not included in the manual procedure. A more detailed discussion of the assumptions and applications of these factors are given in appendix D.

Unit Accident Costs

After estimating expected reduction in utility pole accidents and applying the roadside hazard adjustment, a unit accident cost must be used to compute dollars of accidents savings. Table 8 shows the two most commonly used unit accident costs, those of the National Safety Council (NSC) and the National Highway Traffic Safety Administration (NHTSA).

Table 8: NSC and NHTSA Accident Costs

	NSC (1981)	NHTSA (1975)
Cost per fatality	$190,000	$287,175
Cost per injury	$ 7,200	$ 3,185
Cost per property damage only (PDO) accident	$ 1,020	$ 520

Note that the costs per "fatality" and "injury" (i.e., per person killed or injured), and not per fatal or injury "accident".

Either NSC, NHTSA, or an individual States' accident costs may be used in the manual or computerized cost-effectiveness procedure. However, the NSC costs are used for general assessment of countermeasures, since they are more widely accepted, provide current costs, and assume a more conservative cost for a fatality.

The average cost per utility pole accident can be computed based on the cost per event and the number of injuries and fatalities per injury and fatal accident as summarized in table 9. From an analysis of 9,583 utility pole accidents, the average cost per utility pole "accident" is:

$$\begin{aligned} C_A = {} & (\text{Percent PDO accidents}) \times (\text{Cost/PDO acc.}) \\ & + (\text{Percent injury accidents}) \times (\text{Cost/injury}) \times (\text{Injuries/injury acc.}) \\ & + (\text{Percent fatal accidents}) \times (\text{Cost/fatality}) \times (\text{Fatalities/fatal acc.}) \\ & + (\text{Percent fatal accidents}) \times (\text{Cost/injury}) \times (\text{Injuries/fatal acc.}) \end{aligned} \tag{7}$$

$$\begin{aligned} C_A = {} & (0.527)(\$1{,}020) \\ & + (0.463)(\$7{,}200)(1.31) \\ & + (0.01)(\$190{,}000)(1.08) \\ & + (0.01)(\$7{,}200)(0.7) \\ = {} & \$538 + \$4{,}367 + \$2{,}052 + \$50 \\ = {} & \$7{,}007 \text{ per utility pole accident} \end{aligned}$$

The computer program and manual procedure allow for updating the cost per accident as these numbers change over time.

This cost of $7,007 per utility pole accident compares with costs by Rinde [10] of $6,200 per accident in rural areas and $5,200 per accident in urban areas.

Countermeasure Costs

The costs for utility pole accident countermeasures may be considered in terms of initial countermeasure costs and also the change in annual maintenance costs. For the cost-effectiveness procedure, the initial countermeasure costs can be input by the user if such information is known. If not, average (expected) initial costs are given for each of the countermeasures. These average values do not include costs for additional right-of-way acquisition. Such costs, if applicable, must be added.

Costs are discussed below in terms of the following countermeasures:

- Undergrounding utility lines
- Relocating utility poles further from the roadway
- Reducing pole density
- Conversion to breakaway pole

Table 9. Summary of injuries by accident severity for utility pole accidents.

Accident Severity	Number of Accidents	Number of People Injured	Number of People Killed	People Injured Per Accident	People Killed Per Accident
PDO Accidents	5,050	0	0	0	0
Injury Accidents	4,434	5,796	0	1.31	0
Fatal Accidents	99	69	107	0.70	1.08
Totals	9,583	5,865	107	0.61	0.01

Detailed cost information was obtained from 12 telephone companies in 21 States and 31 electric companies in 20 States for undergrounding projects, pole relocation projects, and projects involving reducing pole density [5]. Costs for breakaway poles were found in the literature [6].

Placing Utility Lines Underground - Placing utility lines underground is a costly and labor-intensive countermeasure for utility pole accidents. Installing utility lines underground is a two-stage process involving pole removal and cable burial. The cost of underground utility lines depends upon the degree of urbanization of the area, the spacing (density) of poles, the location of the poles relative to the roadway or intersection roadways, the size and type of cable to be buried, the proximity of underground utilities (water, storm and sanitary sewer, natural gas, etc.), the method of cable burial (direct burial, use of conduit, etc.) and many other factors.

Underground line costs experienced by large electric companies vary widely from about $20,000 per mile ($12,500 per km) to $1.7 million per mile (1.1 million per km), depending on many different factors. Based on discussions with utility company officials, the variables identified as having the greatest effect on the costs of underground lines were:

- The size and type of power line (i.e., transmission or distribution)
- The method of burial (i.e., direct burial or conduit)
- The size of the utility line (i.e., one phase or three phase line)
- The area type (urban or rural, since burial in an urban area usually involves removing and replacing concrete).
- The type of terrain and soil conditions (i.e., rock, sand, clay).
- Labor and material costs.

To simplify this analysis, costs from various electric companies were summarized by area type (urban or rural) within the following categories:

Group 1: Transmission lines, >69 KV, conduit used
Group 2: Distribution lines, <69 KV, conduit used
Group 3: Distribution lines, <69 KV, direct burial, 3 phase lines
Group 4: Distribution lines, <69 KV, direct burial, 1 phase lines

The average cost for undergrounding of large transmission lines (Group 1) was $1.2 million per mile ($0.75 million per km). For undergrounding distribution lines in conduit (Group 2), costs averaged about $430,000 per mile ($269,000 per km) in rural areas and $650,000 per mile ($406,000 per km) in urban areas [5].

The cost data for undergrounding is expressed in table 10 in terms of average costs and cost ranges. For example, the cost per mile of underground electric distribution lines (less than 69 KV, one phase) in urban areas using the direct bury method ranged from $30,000 to $45,000 per mile ($19,000 to 28,000 per km), with an average cost of $38,000 per mile ($24,000 per km). The cost for undergrounding increases with the size of the line, up to an average cost of $1.3 million per mile ($0.81 million per mile) for undergrounding electric distribution lines.

For use in the cost-effectiveness procedure, site-specific cost estimates for undergrounding should be used. For example, some utility poles may carry multiple lines, such as urban utility poles with two 34 KV circuits and two 12 KV circuits. In such cases, costs shoud be estimated which most closely correspond to site conditions. In the absence of reliable cost information for a site, the average values in Table 8 may be used.

Information was also obtained concerning the differences in maintenance costs which may result from undergrounding of overhead utility lines. For each electric company, the annual maintenance cost was compared between underground lines and overhead lines. Eight agencies reported lower maintenance costs with overhead lines, and six agencies reported lower maintenance costs with underground lines. For example, one company reported a cost savings of $1,000 per mile ($625 per km) per year due to undergrounding whereas two other companies reported a cost increase of $1,000 per mile ($625 per km) per year due to undergrounding. For estimation purposes, costs should be used which have been found to be appropriate for a given area. In the absence of specific maintenance cost information, average maintenance costs for underground lines and overhead lines may be assumed to be about the same [5].

Relocating Poles Further from the Roadway - Costs for relocating poles for electric companies were classified into four categories:

- Wood power poles carrying less than 69 KV
- Non-wood poles (metal, concrete, or other)
- Heavy wood distribution (i.e., 3 phase) and wood transmission poles
- Steel transmission poles, such as steel towers or 6-ft (1.8-m) diameter steel poles

Average costs and a range of costs for pole relocation projects are provided in table 9 for each of the four pole categories. The average relocation costs in rural areas range from $1,270 per pole for small wood power poles to $20,000 per pole for steel transmission poles. Average costs were higher in urban than rural areas, where the cost of relocating steel transmission poles averages $30,000 per pole. Note that costs are

Table 10. Summary of costs for undergrounding utility lines.

Type of Utility Line	Range of Installation Costs (Dollars per Mile)		Average Installation Cost (Dollars per Mile)	
	Rural	Urban	Rural	Urban
Telephone Lines	\$4,450-\$30,817	\$10,500-\$85,000	\$18,000	\$36,000
Electric Distribution Lines <69 KV, Direct Bury, One Phase	\$17,000-\$29,000	\$30,000-\$45,000	\$24,000	\$38,000
Electric Distribution Lines <69 KV, Direct Bury, Three Phase	\$29,000-\$220,000	\$45,000-\$225,000	\$105,000	\$161,000
Electric Distribution Lines <69 KV, Conduit	\$200,000-\$650,000	\$400,000-\$1,050,000	\$430,000	\$650,000
Electric Tramsmission Lines $\geq$69 KV	\$728,000-\$1,728,000	\$728,000-\$1,728,000	\$1,228,000	\$1,228,000

Based on information from 31 utility companies in 20 states throughout the U.S. (1982).

Source: Reference 5.

Table 11. Summary of costs for relocating utility poles.

Type of Utility Poles or Lines	Range of Installation Costs (Dollars per Pole)		Average Installation Cost (Dollars per Pole)	
	Rural	Urban	Rural	Urban
Wood Telephone Poles	$160-$600	$160-$754	$345	$425
Wood Power Poles Carrying <69 KV Lines	$150-$4,000	$150-$4,000	$1,270	$1,440
Non-Wood Poles (Metal, Concrete or Other)	$630-$3,250	$630-3,370	$1,740	$1,810
Heavy Wood Distribution and Wood Transmission Poles	$580-$5,500	$500-$7,100	$2,270	$2,940
Steel Transmission Poles	$10,000-$30,000	$20,000-$40,000	$20,000	$30,000

Based on information from 31 utility companies in 20 states throughout the U.S. (1982).

Source: Reference 5.

given as cost per pole, instead of cost per mile, since the cost is dependent on the number of poles to be moved instead of the miles of digging to be conducted, as with underground burial [5]. Special consideration should also be given to the number and types of lines when developing cost estimates for pole relocation.

Reducing Pole Density - Reducing pole density can involve three subcategories of countermeasures: (1) an increase in utility pole spacing; (2) the use of poles for multiple purposes; or (3) the use of one line of poles instead of two. Increasing the spacing of utility poles is a countermeasure to reduce the number of poles, thereby reducing the chance of a collision. Increasing the pole spacing for safety purposes would most likely require larger poles, since existing pole spacing is based on structural considerations. The results of this countermeasure could be fewer but larger poles, and larger poles may increase the severity of an injury if struck. The cost for increased pole spacing can be approximated by the cost of pole relocation as given in table 11 [5].

Multiple use or sharing of utility poles has long been a standard practice of many utilities. Electric, phone, cable television, lighting, and various communications services often share utility pole as a means of decreasing distribution costs. The total cost would depend on the existing utilities' configuration and the ease with which service lines could be moved.

Although no cost for multiple pole use was found in the literature, input was obtained from utility companies regarding the procedures and costs associated with sharing of telephone, electric, and/or cable television lines. Many different cost arrangements may be made, but different companies may commonly enter into a "pole lease" agreement. For example, in one State, a lease cost of $9 per pole per year is paid by the telephone company to jointly use power poles. The cost of using existing power poles for new telephone lines saves the cost of burying and installing new lines [5].

The costs of relocating an existing phone line to a new line of poles, however, will generally require all new line facilities (to prevent service interruptions). Thus, the costs of installing a phone line in a multiple use situation will conservatively approximate the cost of installing a new line. According to input from nine telephone companies, the costs per mile of a typical installation in rural areas ranges from $1,827 per mile ($1,142 per km) to $19,290 per mile ($12,060 per km), with an average cost of $8,680 per mile ($5,425 per km). In urban areas, the costs range from $2,265 per mile ($1,416 per km) to $24,000 per mile ($15,000 per km), and the average cost is $11,000 per mile ($6,875 per km). These costs assume the relocation of telephone lines (or perhaps small electric lines), since large overhead voltage electric lines would require their own poles and would not commonly be relocated to a telephone pole for multiple use [5].

The use of one line of poles instead of two may involve eliminating poles from one side of the roadway or, if two lines exist on the same side of the roadway, moving the utilities to the line of poles located farthest from the roadway. This countermeasure can include the use of poles for multiple purposes (discussed above) or consolidating utilities from the same company to one line of poles. This countermeasure is basically similar to multiple pole use, and costs are assumed to be comparable to multiple pole use. Maintenance costs may be assumed to remain unchanged after the treatment.

Conversion to Breakaway Poles - The modification of utility poles to break *or shear off under a reduced* shear loading is another countermeasure for which cost information was obtained. Although the development and testing of new breakaway treatments is still being investigated, some cost information was found in the literature for various types of breakaway treatments. For example, one type of modification involves retrofitting by drilling or cutting the utility pole with a predetermined pattern of holes or notches to incorporate the breakaway feature.

Three sources were found in the literature which provided cost estimates for retrofitting breakaway poles. A 1980 study by Mak and Mason [6] obtained information from seven major utility companies, and estimated the cost of retrofitting a utility pole to be $982 per pole, which includes:

$90 - Initial "Retrofit" treatment
$592 - Replacement of pole due to shortened pole life
$300 - Increase in repair/replacement costs due to the higher knockdown probability in the event of a collision
$982 - Total

In a 1979 study by Fox et al. [7] in Australia, the cost of modifying poles to breakaway was estimated to be $5.84 million for 8,347 poles, or about $700 per pole. Other cost estimates were made by Hunter et al. [16] of $36 per pole and Jones and Baum [4] of $40 to $80 per pole.

In summary, the countermeasure of incorporating breakaway features in utility poles has not been fully developed to date, and testing of various breakaway devices continues. Based on current available knowledge, the simple one-time cost of cutting or drilling the pole range from about $36 to $80. However, by including the costs of shortened pole life and pole replacement costs, the cost per pole was assumed to be about $1,000 per pole, as determined by Mak and Mason [6]. The costs of a slipbase are also about $1,000 per pole.

Indirect Costs - The implementation of the various countermeasures could *result in both* direct and indirect costs. Direct costs include construction and maintenance, while indirect costs are not as easily defined or measured. During construction, indirect costs might be incurred by the motorists in the form of increased stops or delay, excess fuel consumption, increased travel time, inconvenience, etc., depending on the type of construction and the location of the construction with respect to the highway right-of-way. Additional expenses will be incurred should detours need to be set up, manned and then taken down.

Indirect costs are also incurred by the utility whose facilities are affected. The utility companies generally fund projects related to relocating or burying of utility lines, and a great deal of administrative costs may be involved. A formidable amount of engineering and planning is encompassed in any relocation effort. In addition, franchise section maps and customer service records would require updating should utility lines be moved. All of these indirect costs are very difficult to quantify.

If undergrounding is utilized, each neighboring utility requires notification to ensure the staking of nearby pipelines, cables, etc., prior to construction. Most States have a one-call alert system which notifies all affected utilities in the event of forthcoming excavation and construction. Also, if large high pressure pipelines or high voltage electric lines are in the vicinity, most utilities require a full-time representative (inspector) to be present during all excavations. Customers of utilities would also be affected if service is interrupted, or if service lines were accidently severed during excavation.

Undergrounding of electric or communication lines can also be quite costly to customers. Additional indirect costs may be incurred by customers to rewire service entrances or to convert to undergrounding service.

These added indirect costs must be weighed against reduced costs which may result from the countermeasures. For example, relocating poles further from the roadway may reduce the chance of a service interruption due to a pole downed by a vehicle-pole accident. The use of breakaway pole bases, however, may increase service interruptions due to a vehicle hit or a storm. Liability costs to the highway agency and possibly the utility company could also be reduced as a result of these countermeasures.

The issue of indirect costs associated with utility pole accident countermeasures is quite complex. Also, indirect costs may change drastically from one site to another for the same type of countermeasure. It may be possible to quantify indirect costs for use in site specific evaluations, and the quantification of indirect costs for a given countermeasure should be included whenever possible.

Other Economic Inputs

Several other economic inputs are also needed to conduct the cost-effectiveness analysis, including:

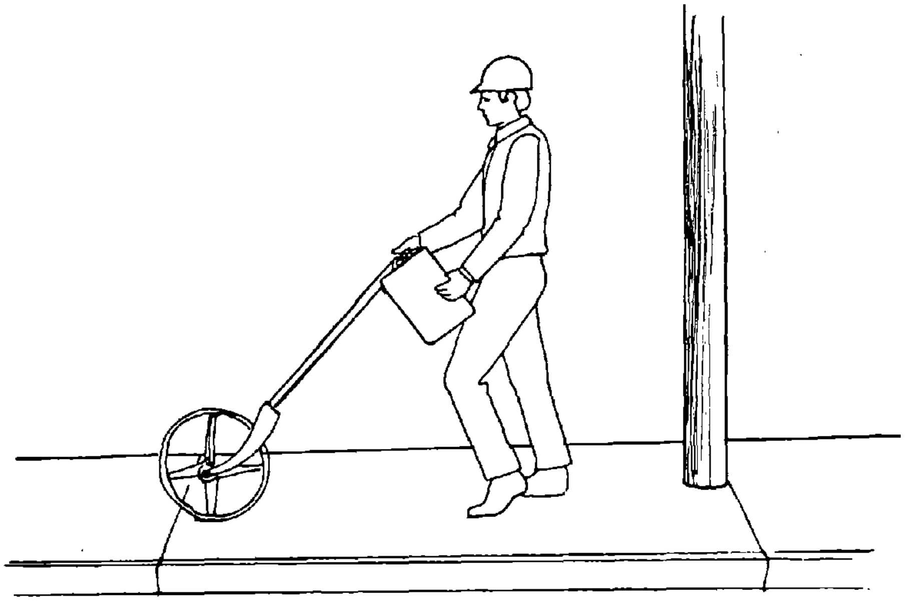
- Project service life
- Salvage value
- Interest rate

The following is a brief discussion of these three factors:

Service Life - For each countermeasure under consideration, service life must be established for use in computing accident benefits. Based on input from telephone and electric companies, average expected service lives of poles were obtained for overhead lines and undergrounding, and generally ranged from 15 to 30 years, depending on the local conditions or types of poles and lines. The user may select any expected service life, although a service life of 20 years is a conservative assumption for most situations.

Salvage Value - The salvage value is the dollar value of a project at the end of its service life. For most highway safety-related projects, the salvage value is very small and is generally assumed to be zero, particularly where long service lives are involved. For utility pole accident countermeasures, salvage values are possible, depending on the condition of the poles and lines. However, this is highly dependent on the specifics of the site. A user may enter a salvage value into the economic analysis. Otherwise, a salvage value of $0 will be assumed.

Interest Rate - The interest rate is an important value input into the cost-effectiveness procedure by the user. For long project service lives (i.e., greater than 15 years), the interest rate could have a considerable effect on the computed benefits. Thus, the attractiveness of the B/C ratio of each project can be affected, which could affect the selection of a particular countermeasure. In recent years, many agencies have used interest rates up to 20 percent. The manual procedure and UPACE program defaults to a 12 percent interest rate when specific information on sites is unavailable.



IV. GUIDELINES FOR COLLECTING INPUT DATA

There are several inputs for the manual or computer cost-effectiveness methods which require field data collection for a site specific analysis. This chapter describes which factors require field or other types of data collection and methods used to collect the data.

The types of data to be collected fall into the following categories:

- Utility pole features
- Roadside features
- Utility pole accident data
- Countermeasure cost information

These guidelines are intended to minimize field data collection activities and not burden the user with difficult or complicated techniques. The details of the data collection will be limited to the requirements of the cost-effectiveness procedures and model.

Utility Pole Features

Utility Pole Offset

This value represents the average lateral distance from the roadway (in feet) to poles on the section. This is one of the most important variables collected in the field. The utility pole accident predictive model is highly sensitive to utility pole offset, and pole offset is particularly important if poles are located within 10 feet (3 m) of the road.

To obtain this data, it is recommended to use a measuring wheel and measure perpendicularly from the edge of the traveled way (or curb face) to the pole to the nearest 1 foot (0.3 m). It is not necessary to measure the offset of every pole. The measurement of 1 out of 5 poles will be sufficient if the poles are in a straight line. If pole offsets vary greatly, more measurements may be needed.

If two lines of poles exist (one on each side of the roadway), the average for both sections combined must be used, unless one line has an offset greater than 30 feet (9 m). An example of calculating average pole offset for a section with two lines of poles (measuring 1 out of 5 poles) is as follows:

Side 1 - 100 poles (20 poles measured)

3 at 4 feet (1.2 m)
10 at 5 feet (1.5 m)
7 at 6 feet (1.8 m)

Side 2 - 80 poles (16 poles measured)

10 at 12 feet (3.6 m)
2 at 13 feet (3.9 m)
4 at 15 feet (4.5 m)

Average Offset

$$= \frac{[(3x4) + (10x5) + (7x6)]\ 5 + [(10x12) + (2x13) + (4x15)]\ 5}{180}$$

$$= \frac{520 + 1{,}030}{180} = 8.6 \text{ feet} = 9 \text{ feet } (2.7 \text{ m})$$

Totally obstructed poles must be excluded from the calculation of average pole offset, since they cannot be struck by a run-off-road vehicle.

Pole Density

This information can be collected by driving the section and counting the number of poles within 30 feet (9 m) of the roadway on the entire section. The number of poles (both sides) divided by the section length in miles gives the pole density. Totally obstructed poles should not be counted when determining pole density.

Pole Line Type

Pole line type can have a major impact on countermeasure costs. Costs to relocate telephone poles or underground the lines will likely be much less than for distribution or transmission lines. The telephone or electric company should be contacted to obtain this information.

Roadside Features

Roadside Coverage Factor (C_F)

The C_F factor is an input to both the manual and computer method. Data for it can be collected as described earlier by driving the section and counting the number of point and line obstacles as shown in table 1. This method is described in greater detail in NCHRP 247 [15]. One caution with this method is if poles are located on one side of the roadway, you do not need to be concerned with fixed objects located on the other side of the roadway. If poles are located on both sides of the roadway, an average coverage factor must be used (since only one value for C_F can be input).

Table 12 indicates the number of point or continuous fixed objects per mile for various coverage factors and was developed by expanding the values in table 1 from the number of fixed objects per 200 feet (60 m) to the number of fixed objects per mile, the following table indicates the number of point or continuous fixed objects per mile. Using table 12 for a location having utility poles on one side, and a roadside with 28 point fixed objects (20 percent coverage factor) and 250 feet (75 M) of continuous fixed objects (20 percent coverage factor), a coverage factor for a one-mile section would be approximately 40 percent. The rules of which objects to count or not count in table 12 are the same as for table 1. The values of C_F should be rounded to the nearest 10 percent.

A preferred method of assigning a roadside coverage factor is to examine figures 12 through 17 which represent roadside coverages of 10, 20, 30, 40, 60, and 80 percent respectively. It is advisable to review these illustrations and select an average value of C_F which most represents the roadside under investigation.

Distance to an Obstructed Zone

This is only used as an input to the computer model. The value is the average lateral offset measured from the edge of the roadway to the obstructed zone in feet. The obstructed zone is a dense collection of fixed objects, such as a dense forest or a continuous wall. If an obstructed zone does not exist, a value of 30 feet (9 m) should be used for rural areas and 20 feet (6 m) for urban areas.

Table 12. Roadside coverage factors (C_F) for various numbers of fixed-objects per mile.

Percent Coverage Factor (C_F)	Number of Point-Obstacles per Mile		Total length of Continuous Objects (ft.)	
	Poles on One Side	Poles on Both Side	Poles on One Side	Poles on Both Sides
10	12	24	0-120	0-240
20	28	56	121-380	241-760
30	45	90	381-840	761-1,680
40	62	124	841-1,400	1,681-2,800
50	79	158	1,401-1,950	2,801-3,900
60	98	196	1,951-2,400	3,901-4,800
70	118	236	2,401-2,900	4,801-5,800
80	139	278	2,901-3,400	5,801-6,900
100	>185	>370	>4,000	>8,000

Note: 1 foot = 0.3 m
1 mile = 1.6 km

Sideslopes

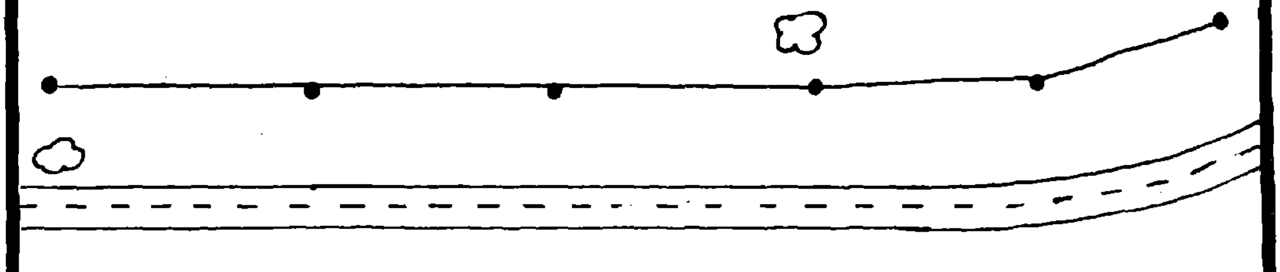
Roadway sideslope (rural areas only) is an important input variable for the computer model. This data can be obtained from agency files or by measurement in the field and is only needed for sections without curbs. The average or predominate value for sideslope should be used as well as a designation for cut or fill. If poles are located on one side of the road, the sideslope value for only that side of the road should be used.

Traffic Volume (ADT)

Traffic volume is an important input to both the manual procedure and the computer model. This data should be obtained from agency files and should represent the average daily traffic volume for the base year. If this data is not available, a 24-hour traffic count should be taken. The user is cautioned that the cost-effectiveness procedure is not applicable for roadway sections with average daily traffic volumes less than 500 or greater than 60,000.

Traffic Growth Projections

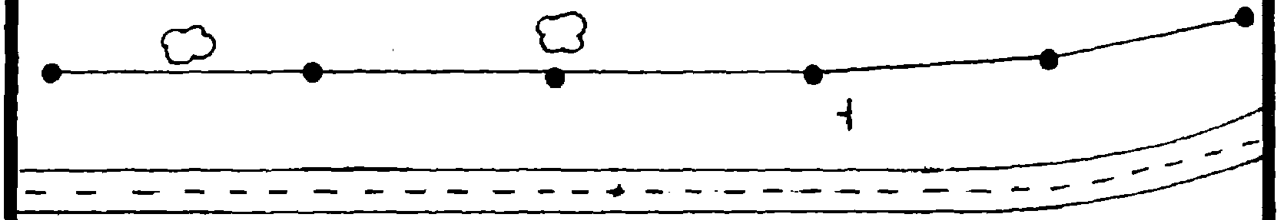
This data should be obtained from agency files and must coincide with the analysis period. The manual method allows for the use of an annual growth factor or an overall growth factor. In addition to these, the computer method allows the user to input the projected traffic volume for each year of the analysis period. This information is needed to allow for future changes in accidents resulting from changes in traffic volume.



Section length = 0.1 mile (0.16 km)

Scale: 1 inch (2.5 cm) = 80 ft. (24 m)

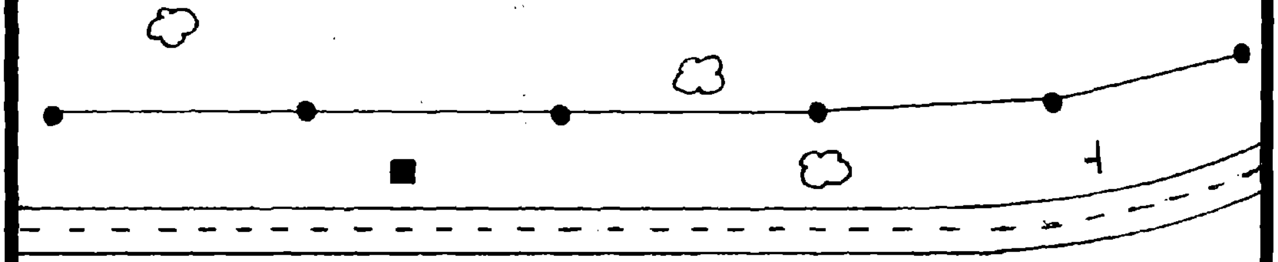
Figure 10. Illustration of roadside with a 10 percent coverage factor (C_F).



Section length = 0.1 mile (0.16 km)

Scale: 1 inch (2.5 cm) = 80 ft. (24 m)

Figure 11. Illustration of roadside with a 20 percent coverage factor (C_F).



Section length = 0.1 mile (0.16 km)

Scale: 1 inch (2.5 cm) = 80 ft. (24 m)

Figure 12. Illustration of roadside with a 30 percent coverage factor (C_F).

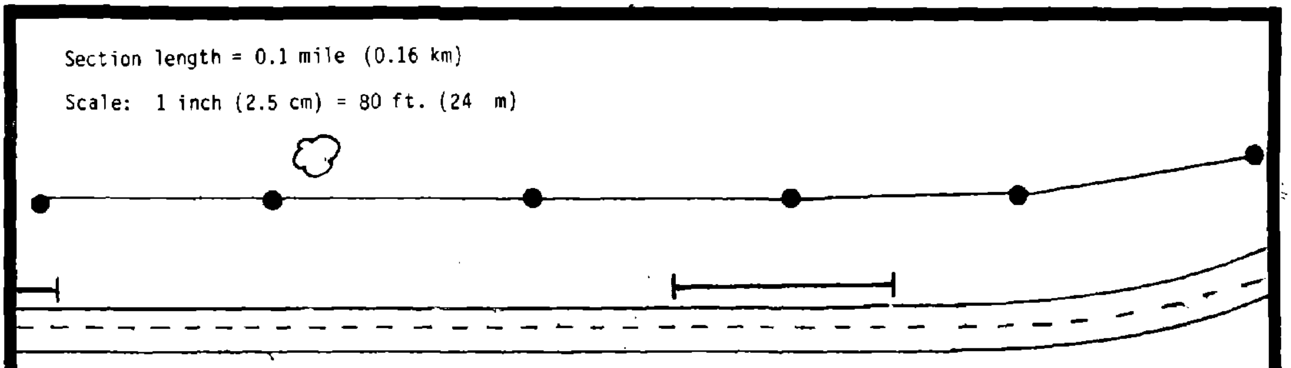


Figure 13. Illustration of roadside with a 40 percent coverage factor (C_F).

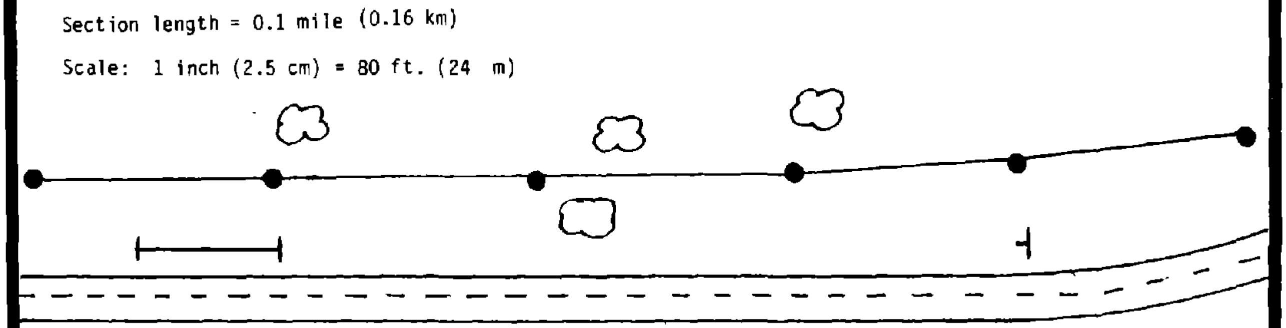


Figure 14. Illustration of roadside with a 60 percent coverage factor (C_F).

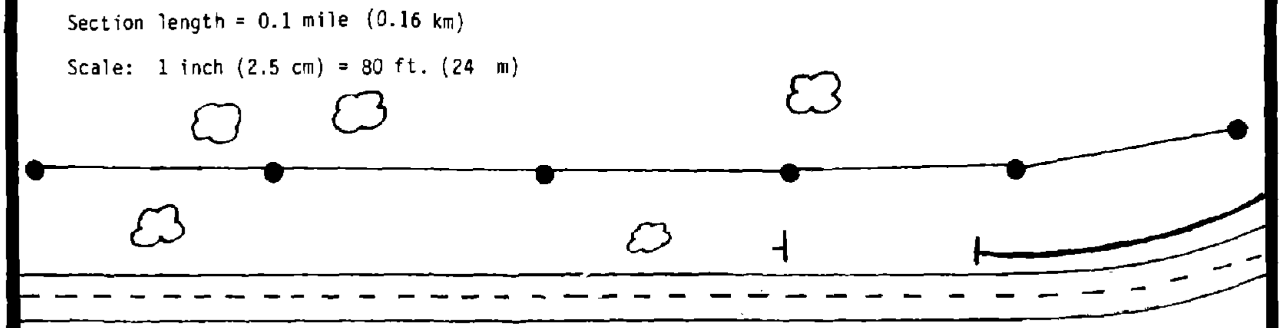


Figure 15. Illustration of roadside with a 80 percent coverage factor (C_F).

Utility Pole Accident Data

The user may prefer to use historical utility-pole accident data on the section instead of the predictive model to obtain baseline accident experience. This is encouraged but is acceptable only if the following conditions are met:

- Accidents must be coded as "utility pole" and not just as "run-off-road." If there is no separate box to indicate that a utility pole was struck, the reporting officer may or may not indicate so.

- There must be a reasonably low reporting threshold (i.e., $400 or less) such that a high percentage of property damage only (PDO) accidents are reported. In some jurisdictions, only tow-away or injury accidents are reported. This type of reporting level would be insufficient for using existing accident data.

- Three to five years of utility pole accident data must be available for analysis purposes. General guidelines are if the traffic volume (ADT) is above 10,000 vehicles and/or the section length is 2 miles (3.2 km) or greater, then 3 years of accident data is probably adequate. Otherwise, 5 years of accident data should be used. Also, if a major change occurred during the past 3 to 5 years (during which accident data are being evaluated), such as a road closure for construction, or modification to the existing pole placement, this is another reason to not use historical accident data.

- The location of the accidents must be accurately recorded. For example, when locational information is consistently in error by 0.1 to 0.5 mile (0.16 to 0.8 km), then historical accident data should not be used.

- There should be at least 5 utility pole accidents found during the analysis period. For sections with less than 5 utility pole accidents, it is preferable to use the predictive model. Since utility pole accidents are random and relatively rare events, fluctuations in utility pole accidents may result in a nonrepresentative accident sample for the section.

The manual and computer procedures have built-in factors to account for accident severity. This will result in a more stable and realistic estimate of accident severity. For example, if actual utility pole accidents are used for the analysis, a single random fatality could result in justifying almost any countermeasure. The assumed distribution of accident severity for a section is 1 percent fatal accidents, 46.3 percent injury accidents, and 52.7 percent property damage only accidents, based on an analysis of 9,583 utility pole accidents on over 2,500 miles (4,000 km) in 4 States [5].

Cost Information

Cost information for each countermeasure is highly site specific. Although tables are provided in this report to show acceptable ranges and average countermeasure costs for a section, these should only be used when better information is not available. Cost-related information should include:

- Direct countermeasure installation costs, including right-of-way acquisition and costs of removing the old line of utility poles

- Indirect costs, such as insurance costs, the cost of power outages, or rerouting traffic (if necessary), and engineering and administrative costs associated with the countermeasure.

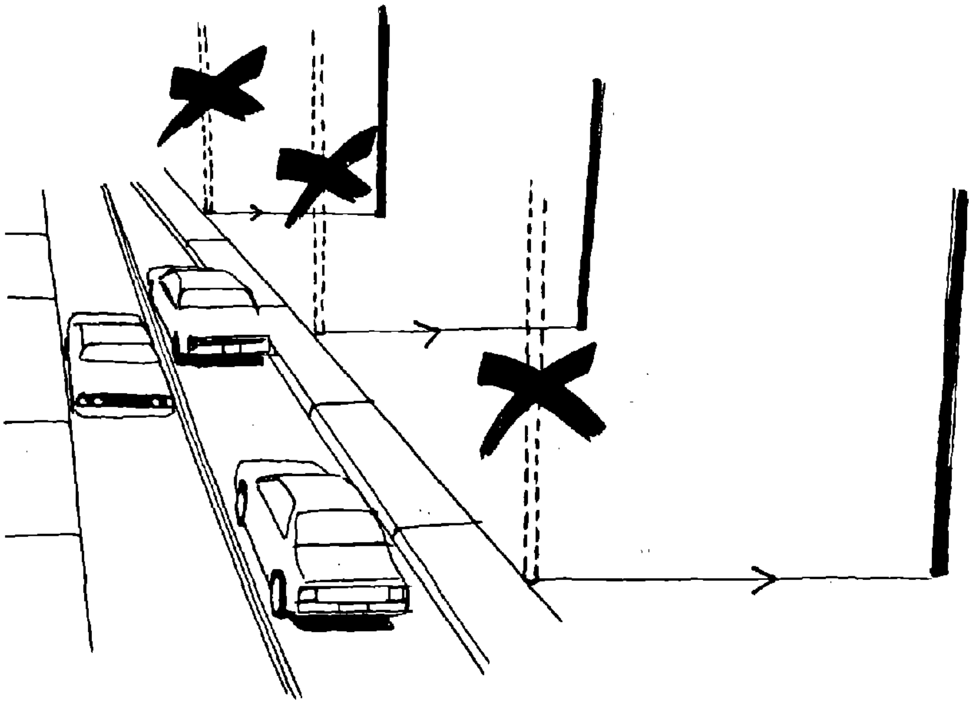
- The change in maintenance costs associated with the countermeasure.

- The service life of the countermeasure.

- The salvage value at the end of the service life (if applicable).

This information can be obtained from the utility company in question or can possibly be obtained by investigating associated costs of similar past projects.

Increasing Pole Offset Reduces Accident Frequency



V. MANUAL COST-EFFECTIVENESS PROCEDURE

This procedure may be used to manually determine the cost-effectiveness of each proposed countermeasure, and to determine which alternative is optimal when two or more alternatives are under consideration. The manual procedure involves a site-specific analysis where actual accident experience and individual agency costs can be used for countermeasure implementation and maintenance, as well as agency interest rates, and other inputs. The manual procedure can be utilized with the aid of tables, nomographs, worksheets, and a calculator, without the aid of a computer.

The manual procedure is a simplified version of the computerized cost-effectiveness procedure, but does not allow for the use of some details such as projected safety belt use or vehicle downsizing in future years. In addition, the computer method allows for more detailed calculations of the roadside adjustment factor, computation of future traffic volumes, projected utility pole accident occurrence and severity, etc. compared to the manual cost-effectiveness method.

A series of 18 steps are provided for conducting the manual procedure. In addition, a series of work forms are provided to assist in the procedure. Form A (figure 16) is used to summarize the existing conditions at the site, and form B (figure 17) is used to describe the charac-

COST-EFFECTIVENESS ANALYSIS PROCEDURE FOR UTILITY POLE ACCIDENTS

FORM A: SITE DESCRIPTION

Road Name or Route Identification: ______________________________

Beginning Milepoint: _________ Ending: _________ Length: ________ (Miles)

Area Type (Urban or Rural) _______________ Curb (Yes or No) ________

Right-of-Way Width: ______________ Shoulder Width: ____________ Feet

Current Daily Traffic Volume (ADT_C): ________ Speed Limit: _______ mph.

Expected Future Change in ADT = ___ percent/yr. or ___ percent in ___ yrs.

Utility Pole Location (one side or two): ______________

	No. of Poles	Pole Spacing	Poles/Mile	Avg. Pole Offset
Side 1:	________	________ ft.	________	________ ft.
Side 2:	________	________ ft.	________	________ ft.
Total:	________		________	________ ft.

<u>Type of Utility Poles and Lines:</u>

Side 1	Side 2 (if applicable)	
____	____	Wood telephone poles
____	____	Wood power poles carrying <69 KV lines
____	____	Non-wood poles
____	____	Heavy wood distribution and transmission poles
____	____	Steel transmission poles

Utility Pole Accident Data: ☐ Available ☐ Not Available

Utility Pole Accidents = _________ (total) for ____ years.

Utility Pole Accidents/Mile/Year (A_C) = $\frac{\text{No. of Utility Pole Accidents}}{\text{(Sec. Length) x (Yrs. of Data)}}$

A_C = _____ Utility Pole Accidents per mile per year

Percent injury & fatal Utility Pole Accidents = _____ %

Total Injuries: ______________ Total Fatalities: _____________

Coverage of other heavy fixed objects within 30 feet of roadway. Refer to Figures 10 to 15 to determine coverage factor (C_F) to use (check one):

____ 10% Roadside Coverage (See Figure 10)
____ 20% Roadside Coverage (See Figure 11)
____ 30% Roadside Coverage (See Figure 12)
____ 40% Roadside Coverage (See Figure 13)
____ 60% Roadside Coverage (See Figure 14)
____ 80% Roadside Coverage (See Figure 15)

Figure 16. Work form A: site description.

COST-EFFECTIVENESS ANALYSIS PROCEDURE FOR UTILITY POLE ACCIDENTS

FORM B: COUNTERMEASURE DESCRIPTION

(Complete Form B for Each Countermeasure)

Countermeasure Number ____of____

Countermeasure to be Evaluated (Check One):

_____ Placement of Utility Lines Underground (Check One)

_____ Telephone lines
_____ Electric distribution lines <69 KV, direct bury, one phase
_____ Electric distribution lines <69 KV, direct bury, three phase
_____ Electric distribution lines <69 KV, conduit
_____ Electric transmission lines >69 KV
_____ Other:______________________________

_____ Pole Relocation from ____ feet to ____ feet from the edge of the pavement

_____ Increase Pole Spacing from____ to ____ feet. Thus the total number of poles on the section will be ____________ which translates to___________ poles per mile of roadway section.

_____ Pole Relocation from _____ feet to _____ feet from the edge of the roadway and Increase Pole Spacing to _____ feet which translates to _____ poles per mile of roadway section.

_____ Add Breakaway Pole Feature to _____ percent of poles. Expected reduction in injury and fatal accidents = _____%

_____ Multiple Pole Use (for a section with utility poles on both sides of the roadway) by removing utility lines from the line of poles closest to the roadway. The average offset of the remaining line of utility pole is ____feet from the edge of the roadway. The number of poles on the section would be ____ translating to ____poles per mile of section.

Expected change in annual maintenance cost (total section):

_____ No change
_____ Increase of $_____ per year
_____ Decrease of $_____ per year
_____ Unknown (assume $0 change if unknown)

Expected initial project costs (Specify):

$__________ Per Mile:______________________________
$__________ Per Pole:______________________________
$__________ Total:______________________________

Expected countermeasure service life = _____ years (assume 20 years if unknown)

Interest rate = ______ percent per year (assume 12 percent if unknown)

Figure 17. Work form B: countermeasure description.

teristics of each proposed countermeasure. Work form C (figure 18) is used to evaluate the effectiveness of each countermeasure and form D (figure 19) is used to select the most cost-effective countermeasure. The manual procedure is conducted by completing the following steps:

1. Complete the Site Description Form (form A).
2. Complete the Countermeasure Description Form (form B).
3. Compute Average Traffic Volume Over the Project Life (ADT_A).
4. Determine the Number of Utility Pole Accidents Without Treatment (A_B).
5. Determine the Accident Reduction Factor (R_A).
6. Select the Roadside Adjustment Factor (H_R).
7. Compute the Number of Accidents Reduced (ΔA).
8. Select the Average Cost per Utility Pole Accident (C_A).
9. Compute Accident Benefits Due to Reduced Accidents (B_A).
10. Compute Accident Benefits Due to Reduced Accident Severity (B_S).
11. Compute Total Accident Benefits (B_T).
12. Determine the Change in Maintenance Costs (C_M).
13. Determine Countermeasure Installation Costs (C_I).
14. Calculate Total Project Costs (C_T).
15. Calculate the Benefit-To-Cost Ratio (B/C).
16. Conduct Incremental Benefit-to-Cost Ratio Analysis ($\Delta B/\Delta C$).
17. Evaluate Available Funding and Other Constraints.
18. Record Project Details.

The details of each step are described in the following paragraphs.

Step 1 - Complete the Site Inventory Form (form A)

The characteristics of each site should be recorded on form A, which is shown as figure 16. Each site should be relatively homogeneous in features such as traffic volume, pole offset from the roadway, pole spacings and the predominant roadside features. If conditions along a section change considerably, the sections should be divided and a separate analysis should be conducted on each section. For example, assume that the average pole offset is about 2 feet (0.6 m) for 2 miles (3.2 km) of a 5-mile (8-km) section, and the average pole offset is about 10 feet (3 m) for the other 3-mile (4.8-km) segment. In that case, a separate analysis should be made for the 2-mile (3.2-km) section and the 3-mile (4.8-km) section. Minor fluctuations in traffic volume, pole offset and other

COST-EFFECTIVENESS ANALYSIS PROCEDURE FOR UTILITY POLE ACCIDENTS

FORM C: WORK FORM

(Complete Form C for Each Countermeasure: See Coding Instructions)

STEP 1 - Complete the Site Inventory Form (Form A).

STEP 2 - Complete the Countermeasure Description Form (Form B). One Countermeasure Description Form should be completed for each countermeasure.

Countermeasure No.:__________

Countermeasure Description: ______________________________

STEP 3 - Compute Average Traffic Volume over the Project Life (ADT_A)

Current ADT = ______ = ADT_C

- Method 3-A - Annual Growth Rate (g)

Annual Traffic Growth Rate (g) = ____ percent

Adjustment Factor = ______ = F_A (From Table 11)

$ADT_A = (ADT_C) \times F_A$ = ______x______ = ________

- Method 3-B - Overall Growth Rate (G)

Overall Growth Rate (G) = ___ percent

$ADT_A = ADT_C \frac{(2 + G/100)}{2} = \_\_\_\_\_ \frac{(2 + \_\_/100)}{2} = \_\_\_\_\_$

STEP 4 - Determine Utility Pole Accidents Without Treatment (A_B)

- Method 4-A - Accident Predictive Model - Nomograph

ADT_A = _________ (Step 3)

Existing Pole Density = __________ poles/mile (Form A)

Existing Pole Offset = __________ feet (Form A)

A_B = ___________ Accidents per mile per year (Nomograph, Figure 8)

Note: If Method 4-A is used, $A_2 = A_B$.

Figure 18. Work form C: cost-effectiveness evaluation.

COST-EFFECTIVENESS ANALYSIS PROCEDURE FOR UTILITY POLE ACCIDENTS

FORM C: WORK FORM

(Complete Form C for Each Countermeasure: See Coding Instructions)

- Method 4-B - Existing Accident Data

A_C = ______ accidents per mile per year based on existing accident experience (Form A)

Adjustment Factor to Convert Utility Pole Accident Experience From A_C to A_B

A_1 (From Nomograph, Figure 8) = __________

ADT_C = __________ (Form A)
Existing Pole Density = _______ poles/mile (Form A)
Existing Pole Offset = _______ feet (Form A)

A_2 (From Nomograph, Figure 8) = __________

ADT_A = __________ (Step 3)
Existing Pole Density = __________ poles/mile (Form A)
Existing Pole Offset = __________ feet (Form A)

$A_B = (A_C) \times (A_2/A_1)$ = ___ x (___/___) = ____ Accidents per mile per year

STEP 5 - Determine the Accident Reduction Factor (R_A) for utility pole accidents

A_F (from Nomograph, Figure 8) = __________ Accidents per mile per year

ADT_A = __________ (Step 3)
Proposed Pole Density = __________ poles/mile (Form B)
Proposed Pole Offset = __________ feet (Form B)

A_2 = __________ Accidents per mile per year (Step 4)

$R_A = \frac{A_2 - A_F}{A_2}$ = ______ - ______ = ________

R_A = ________ % Reduction in Utility Pole Accident Frequency

For the Breakaway Pole Countermeasure, Skip Steps 6 and 7, go to Step 8.

STEP 6 - Select the Roadside Adjustment Factor (H_R)

Skip for the Breakaway Pole Countermeasure

Coverage Factor (C_F) = ____________ (Form A)

H_R = _______ (0 to 1.0) from Tables 3, 4, 5 or 6.

Figure 18. Work form C: cost-effectiveness evaluation (Continued).

COST-EFFECTIVENESS ANALYSIS PROCEDURE FOR UTILITY POLE ACCIDENTS

FORM C: WORK FORM

(Complete Form C for Each Countermeasure: See Coding Instructions)

STEP 7 - Compute the Number of Accidents Reduced (ΔA)

$\Delta A = (A_B) \times (R_A) \times (H_R) \times (L)$

$\Delta A = \underline{\qquad} \times \underline{\qquad} \times \underline{\qquad} \times \underline{\qquad} = \underline{\qquad}$ Accidents per year

STEP 8 - Select the Average Cost Per Utility Pole Accident (C_A)

C_A = $7,007 based on 1981 NSC costs or $\$\underline{\qquad}$ based on $\underline{\qquad}$

$\underline{\qquad\qquad\qquad\qquad\qquad\qquad}$ agency costs.

For the breakaway pole countermeasure, skip Step 9 and go to Step 10B

STEP 9 - Compute Accident Benefits Due to Reduced Accident Occurrences (B_A)

$B_A = (\Delta A) \times (C_A)$

$B_A = \underline{\qquad} \times \$\underline{\qquad} = \$\underline{\qquad}$ per year.

STEP 10 - Compute Accident Benefits Due to a Reduction in Accident Severity (B_S)

- Step 10-A - For all countermeasures except breakaway devices. Only for sections having speeds less than 45 mph.

  $B_S = (A_B) \times (1 - H_R) \times (R_A) \times (\Delta C_A) \times (L)$ [For ΔC_A, See Table 12]

  $B_S = \underline{\qquad} \times (1 - \underline{\qquad}) \times \underline{\qquad} \times \$\underline{\qquad} \times \underline{\qquad} = \$\underline{\qquad}$ per year

- Step 10-B - For the breakaway pole countermeasure only

  $B_S = (A_B) \times (\Delta C_A) \times (L)$ [For ΔC_A, See Table 13]

  $B_S = \underline{\qquad} \times \$\underline{\qquad} \times \underline{\qquad} = \$\underline{\qquad}$ per year

STEP 11 - Compute Total Accident Benefits (B_T)

$B_T = B_A + B_S$

$B_T = \$\underline{\qquad} + \$\underline{\qquad} = \$\underline{\qquad}$ per year

Figure 18. Work form C: cost-effectiveness evaluation (Continued).

COST-EFFECTIVENESS ANALYSIS PROCEDURE FOR UTILITY POLE ACCIDENTS

FORM C: WORK FORM

(Complete Form C for Each Countermeasure: See Coding Instructions)

STEP 12 - Determine the Change in Maintenance Costs (C_M)

C_M = $______ per year. Use $0 if unknown

STEP 13 - Determine Countermeasure Installation Costs (C_I)

- Method 13-A - Cost Per Mile (C_L)

  $C_I = (C_L) \times (CRF^i_n) \times (L)$

  C_I = $______ x ______ x ______ = $______ per year

- Method 13-B - Cost Per Utility Pole (C_P)

  $C_I = (C_P) \times (P_L) \times (CRF^i_n) \times (L)$

  C_I = $______ x ______ x ______ x ______ = $______ per year

- Method 13-C - Total Project Cost (C_S)

  $C_I = (C_S) \times (CRF^i_n)$ $______ x ______

  C_I = $________ per year

STEP 14 - Calculate Total Project Cost (C_T)

$C_T = C_M + C_I$

C_T = $______ + $______ = $______ per year.

STEP 15 - Calculate the Benefit-To-Cost Ratio (B/C)

$B/C = \frac{B_T}{C_T} =$ ______

Figure 18. Work form C: cost-effectiveness evaluation (Continued).

COST-EFFECTIVENESS ANALYSIS PROCEDURE FOR UTILITY POLE ACCIDENTS

FORM D: COMPARISON OF COUNTERMEASURE

(Use This Form Only if 2 or More Countermeasures Are
Being Considered at the Same Location)

STEP 16 - Conduct Incremental Benefit-to-Cost Ratio Analysis ($\Delta B/\Delta C$).

List the Countermeasures in Order by Cost (C_T) from Lowest to Highest for those with a B/C ratio greater than 1.0 (or other acceptable minimum value).

Rank	Counter-measure Number	Total Annual Cost (C_T)	Total Annaul Benefits (B_T)	B/C Ratio	Compare	Incremental Change In Costs (ΔC)	Incremental Change In Benefits (ΔB)	Incremental Benefit/Cost Ratio $\Delta B/\Delta C$
Lowest Cost (C_T)								
2nd Lowest Cost								
3rd Lowest Cost								
4th Lowest Cost								
Highest Cost								

STEP 17 - Evaluate Available Funding and Other Agency Constraints

Select the remaining countermeasure with the highest incremental benefits to highest incremental costs.

Countermeasure No. and Description: ______________________________

Countermeasure Cost: $______________ per year

Is funding available to complete project (Yes or No) ________

Do any other agency constraints prohibit implementation (Yes or No) ________

If yes, Describe: ______________________________

If the project is unacceptable, select the countermeasure with the next highest incremental benefits to incremental costs until project is selected.

Countermeasure No. and Description: ______________________________

Countermeasure Cost: $______________ per year

STEP 18 - Record Project Details

Selected Project: ______________________________

Project Cost: $______________ per year

Total Project Cost: $____________ Change in Annual Maintenance Costs: $____________

Annual Accident Benefits: $______________

Utility Pole Accidents Reduced per year: ____________

B/C Ratio = ______________

Figure 19. Work form D: comparison of countermeasures.

roadside conditions can be tolerated for a site, without sacrificing much accuracy.

When sections must be broken up for analysis purposes, avoid making section lengths too small. A minimum section length of 0.5 to 1.0 miles (0.8 to 1.6 km) is recommended. Longer sections are preferable (as long as traffic and roadway conditions are relatively uniform) to avoid inaccuracies in matching accidents to a section.

For sections with poles on both sides of the roadway, the overall average pole offset must be used. For example, a two sided section has poles at an average of 5-foot (1.5-m) offsets with 40 poles per mile (25 poles/km) on one side and 15-foot (4.5-m) offsets with 55 poles per mile (34 poles/km), the overall offset would be calculated as follows:

$$\frac{(55 \text{ poles} \times 15 \text{ feet}) + (40 \text{ poles} \times 5 \text{ feet})}{90 \text{ poles}} = 11 \text{ ft } (3.3 \text{ m}) \text{ offset}$$

When determining pole density (poles/mile), count the total number of poles and divide by the section length. Do not include totally obstructed poles which vehicles could not possibly hit. Totally obstructed poles must be considered, however, when computing countermeasure costs on a cost per pole basis.

Step 2 - Complete the Countermeasure Description Form (form B)

Each proposed countermeasure should be described by completing the Countermeasure Description Form (form B) shown as figure 17. One form should be completed for each countermeasure. Costs can be recorded as costs per mile, costs per pole or total costs. All related project costs should be included.

Step 3 - Compute the Average Daily Traffic Volume Expected Over the Project Life (ADT_A)

The purpose of this step is to determine the average traffic volume over the project life. This can be accomplished by one of two methods; (A) by estimating a fixed growth rate per year, such as 5 percent per year or (B) by estimating the overall growth factor over the project life, such as 20 percent over 20 years.

Method 3-A - To determine the average traffic volume (ADT_A) based on a yearly growth rate (g) for a given service life (n), use Table 11 to determine the adjustment factor (F_A). The adjustment factor for traffic volume can also be computed based on a yearly increase in traffic volume from the following expression:

$$F_A = \frac{1 + (1+g/100)^n}{2} \qquad (7)$$

Where:

F_A = The adjustment factor for traffic volume for an annual traffic growth rate
g = Annual traffic growth rate
n = Project service life (years)

Multiplying the existing traffic volume by the adjustment factor (F_A) will provide the average traffic volume over the project period (ADT_A).

The problem with this method is that a given growth rate applied to a facility for a 20 to 25 year period may be unrealistic and may over-estimate future traffic volumes. The shaded portion of table 13 indicates the adjustment factors which may be unrealistically high. These factors in the shaded area may only be applicable to areas which will experience considerable growth for a long period of time. If the adjustment factor falls into the shaded portion of table 13, it may be advisable to use Method 3-B.

Method 3-B - This method applies an overall growth rate (G) to the traffic volume for the entire project period (n). The average traffic volume (ADT_A) is found as follows:

$$ADT_A = ADT_C \left(\frac{2 + G/100}{2}\right) \qquad (8)$$

Where:

ADT_A = Average traffic volume over the life of the project
ADT_C = The existing traffic volume
G = The growth rate in traffic volume for the project service life (n)

Step 4 - Determine the Number of Utility Pole Accidents Without Treatment (A_B)

The number of utility pole accidents per mile per year without treatment can be determined by two methods: (A) by nomograph or (B) actual accident experience.

Method 4-A - The nomograph should be used when the actual historic utility pole accident experience for a section is unknown, the data quality is questionable or if less than three to five years of utility pole accident experience is known for the section. The

Table 13. Adjustment factors (F_A) for determining average daily traffic volumes (ADT_A).

Annual Traffic Growth Rate (g)	Project Service Life in Years (n)							
	5	10	15	20	25	30	35	40
- 5%	0.89	0.80	0.73	0.70	0.64	0.61	0.58	0.56
- 3%	0.93	0.87	0.82	0.77	0.73	0.70	0.67	0.65
- 2%	0.95	0.91	0.87	0.83	0.80	0.77	0.75	0.72
0% (no change)	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
+ 2%	1.05	1.11	1.17	1.24	1.32	1.41	1.50	1.60
+ 3%	1.08	1.17	1.28	1.40	1.55	1.71	1.91	2.13
+ 5%	1.14	1.31	1.54	1.83	2.19	2.66	3.26	4.02
+ 7%	1.20	1.48	1.88	2.43	3.21	4.31	5.84	
+ 8%	1.23	1.58	2.09	2.83	3.92	5.53		
+10%	1.30	1.80	2.59	3.86	5.92			
+12%	1.38	2.05	3.24	5.32				

nomograph in Figure 8 was developed by Zegeer, et al. [5] in a FHWA study of utility pole accidents. The nomograph predicts utility pole accidents per mile per year based on traffic volume, lateral pole offset and utility pole density. To use the nomograph, enter the X-axis with the future traffic volume (ADT_A) from step 2 and proceed vertically to the curve corresponding to the average pole density on a section. Turn at the pole density line (poles/mile) and proceed right to the curve corresponding the pole offset (feet). Turn and proceed down to record the corresponding utility pole accidents per mile per year.

Method 4-B - If the user knows the accident experience for at least 3 years on the section, this data can be used to calculate A_B. First, the existing utility pole accident experience must be converted to the units of utility pole accidents per mile per year (A_C). This number must be multiplied by an adjustment factor to represent the utility pole accident experience for the average traffic volume over the project period (ADT_A) in the untreated condition. To obtain the adjustment factor, determine the expected current utility pole accident experience (A_1) from the nomograph in figure 8 using existing traffic volume (ADT_C) and existing pole offsets and density. Then determine the future projected utility pole accident experience (A_2) from the nomograph in figure 8 using the average traffic volume over the project period (ADT_A). Thus, the number of utility pole accidents in the untreated (before) condition is calculated as:

$$A_B = (A_C) \times (A_2)/(A_1) \tag{9}$$

Where:

A_B = The number of utility pole accidents per mile per year in the untreated (before) condition based on average traffic volume over the project period.

A_C = The actual number of utility pole accidents per mile per year for at least 3 to 5 years of data.

A_1 = The number of utility pole accidents per mile per year using the nomograph based on existing traffic volume (ADT_C).

A_2 = The number of utility pole accidents per mile per year using the nomograph based on the projected average traffic volume (ADT_A).

If the actual number of utility pole accidents are used to determine AB, compare this number with the expected utility pole accidents from the nomograph. If the two values differ greatly, try to determine the reason (i.e., poor accident reporting, unusually dangerous section, etc.). If the actual accident experience fluctuates widely, it may have been due to an unusual occurrence in one year, such as an ice storm, a change in accident reporting level, or other circumstances. If a large fluctuation in accident data is evident, or if only one or two years of accident data are available, then the utility pole accident experience generated from the nomograph should be used. If the accident experience for a section is consistent but much lower than that predicted by the nomograph, this may be due to an unrealistically high reporting level (such as injury accidents only or tow-away accidents being used as a reporting threshold). If it is reasonably certain that the existing utility pole accident experience (A_C) is complete and accurate, this should be used to compute the value A_B (utility pole accidents per mile per year without treatment). If actual utility pole accidents are unknown or of questionable accuracy, then the nomograph value must be used for the value A_B.

Step 5 - Determine the Accident Reduction Factor (R_A)

Use the corresponding accident reduction factor for the respective countermeasure:

- Underground utility lines: $R_A = 1.0$ (100 percent of the utility pole accidents will be eliminated). Proceed to step 6.
- Relocate the poles further from the roadway: proceed to step 5-A to determine R_A.
- Reduce the number of utility poles (multiple pole use, increase pole spacing, etc.): proceed to step 5-A to determine R_A.
- Combination of pole relocation and reducing the number of utility poles: proceed to step 5-A to determine R_A.
- Install breakaway poles: $R_A = 0$ (The number of utility pole accidents will remain unchanged). Skip steps 6 and 7 and proceed to step 8.

Step 5-A - This step is to be used for any combination of pole relocation, and/or reducing the number of utility poles. Use the nomograph in figure 8 to determine the untreated number of utility pole accidents per mile per year (A_B) based on average traffic volumes over the project period (ADT_A) and existing utility pole offset (feet) and density (poles per mile). If actual accident experience is used, the utility pole accident experience in the before condition must be calculated using the nomograph (A_2). Use the nomograph a second time with the same traffic volume (ADT_A), and enter the proposed utility pole offset and density which would exist with the countermeasure to find the expected future utility pole accident experience (A_F). The accident reduction factor (R_A) is computed as follows:

$$R_A = \frac{A_2 - A_F}{A_2} \tag{10}$$

Where:

R_A = Accident reduction factor for utility pole accidents.

A_2 = The number of utility pole accidents per mile per year in the untreated condition based on average traffic volumes (ADT_A) calculated from the nomograph (regardless if existing accident data is used).

A_F = The number of utility pole accidents per mile per year expected after countermeasure implementation based on average traffic volumes (ADT_A) calculated from the nomograph in figure 8.

The value of the accident reduction factor (R_A) must be between 0 and 1.0.

Step 6 - Select A Roadside Adjustment Factor (H_R)

The roadside adjustment factor is used to account for the increase in other run-off-road, fixed-object accidents that would likely have been utility pole accidents (i.e., run-off-road vehicles hit trees that would have been screened by the line of utility poles). The roadside adjustment factor is computed based on the predominant roadside slope, area type, pole offset, roadside coverage factor and other factors. For the manual procedure, the most important input to the process of selecting the roadside adjustment factor is the roadside coverage factor. Some general guidelines for selecting the roadside coverage factor (C_F) for fixed-objects are shown in table 1. Figures 10 through 15 show examples of roadsides having various coverage factors from 10 percent to 80 percent. These figures should be used to estimate the C_F. Tables 3 through 6 will then be used to determine the roadside adjustment factor (H_R) based on the roadside coverage factor and the type of countermeasure. For more details on determining a coverage factor, refer to NCHRP Report 247, "Effectiveness of Clear Recovery Zones" [15].

The roadside adjustment factor (H_R) will be between 0 and 1.0. If H_R is equal to 1.0, this infers that there will be no increase in "other" run-off-road fixed-object accidents, since the roadside is level and absent of other fixed-objects. A roadside adjustment factor close to zero indicates a hazardous roadside where only a small net reduction in total run-off-road accidents will occur.

Step 7 - Compute the Number of Accidents Reduced (ΔA)

The net number of accidents reduced per year is computed as follows:

$$\Delta A = (A_B) \times (R_A) \times (H_R) \times (L) \qquad (11)$$

Where:

ΔA = The net number of accidents reduced per mile per year.

A_B = The number of utility pole accidents per mile per year before treatment (Step 4).

R_A = The accident reduction factor (Step 5).

H_R = The roadside adjustment factor (Step 6).

L = Section length in miles (Form A)

Step 8 - Select the Average Cost Per Utility Pole Accident (C_A)

Based on previous research [5] the average cost for utility pole accidents was determined to be $7,007. This is based on 1981 NSC accident costs and an average of 47.3 percent injury plus fatal utility pole accidents. The average severity was based on an analysis of 9,583 utility pole accidents. The use of an average percentage of injury plus fatal utility pole accidents (47.3 percent) is recommended instead of the actual severity of accidents at the site, since severity is partly a function of factors such as occupant restraint use, passenger health, and type of vehicle, which are not site-related. Also, one fatal accident at a site could inappropriately be used to justify nearly any type of countermeasure. A different value can be used for C_A based on NHTSA accident costs or the individual State's cost. The formulation illustrated in Chapter III under unit accident costs shows how the average cost of a utility pole accident (C_A) was derived. Individual agency costs can be supplemented for the 1981 NSC accident costs to obtain a different value for C_A.

Step 9 - Compute the Accident Benefits Due to a Reduction in Accident Occurrence (B_A)

This step should be conducted for all countermeasures which are expected to affect the frequency of utility pole accidents, which include undergrounding, pole relocation, multiple pole use, or increasing pole spacing. For the breakaway pole countermeasure, skip to Step 10-B. Accident benefits due to a net reduction in accidents are calculated on a yearly basis as follows:

$$B_A = (\Delta A) \times (C_A) \qquad (12)$$

Where:

B_A = Accident benefits per year based on the net reduction in accident occurrences.

A = The net reduction in accidents (Step 7).

C_A = The average cost of a utility pole accident (Step 8).

Step 10 - Compute Accident Benefits Due to a Reduction in Accident Severity (B_S).

For the countermeasures of undergrounding, increasing lateral pole offset, multiple pole use or increasing pole spacing go to Step 10-A. For the breakaway pole countermeasure, go to Step 10-B.

Step 10-A - This step applies only to undergrounding, increasing pole offset, or reducing pole density. If H_R is less than 1.0, that means a portion of the utility pole accidents eliminated will be converted to other run-off-road accidents after countermeasure installation. However, since the severity of utility pole accidents is generally greater than the severity of other run-off-road accidents, (except for rollover accidents), benefits due to a reduction in accident severity can be expected. If H_R is equal to 1.0, then no increase in other run-off-road accidents is expected, and B_S will be equal to 0.

Depending on the area type (rural or urban) the posted speed limit and the predominate types of other fixed objects, the expected reduction in accident severity is about 40 percent for non-utility pole run-off-road accidents. Thus the cost of other run-off-road accidents (ΔC_A) relating to various reductions in accident severity can be determined from table 14. Previous research on utility pole accidents [5] has determined that the difference in cost between utility pole accidents and run-off-road fixed-object accidents in urban areas and where posted speeds are less than 45 mph (72 km/h) is about $2,400. For rural areas, where speeds are 45 mph (72 km/h) or higher, there was little evidence to suggest a difference in accident severity between utility pole and other fixed-object accidents, therefore ΔC_A would be equal to zero and there would be no expected benefits due to a reduction in accident severity ($B_S = 0$).

If ΔC_A is not equal to zero (table 14), then the accident benefits due to reduction in accident severity for utility pole accidents converted to other run-off-road accidents is computed as follows:

$$B_S = (1-H_R) \times (A_B) \times (R_A) \times (\Delta C_A) \times (L) \qquad (13)$$

Where:

B_S = Accident benefits per year due to a reduction in accident severity for utility pole accidents converted to run-off-the-road accidents.

H_R = The roadside adjustment factor (Step 6)

A_B = The number of utility pole accidents per mile per year (Step 4).

R_A = The utility pole accident reduction factor (Step 5)

ΔC_A = The difference in cost between utility pole accidents and other run-off-road accidents (table 14)

L = Section length in miles (Form A)

The actual number of utility pole accidents converted to run-off-road accidents (A_{ROR}) is computed as:

$$A_{ROR} = (1-H_R) \times (A_B) \times (R_A) \times (L) \qquad (14)$$

Step 10-B - This step applies only to the use of breakaway utility pole devices. For breakaway devices, there would be no change in accident frequency ($B_A = 0$), but there would be an expected reduction in utility pole accident severity. Since the in-service evaluation of breakaway pole effectiveness has not been demonstrated, a range of effectiveness can be used. Since the average percent injury and fatal utility pole accidents is 47.3, this should be used as the upper limit. The lower boundary is recommended to be 35 percent injury plus fatal accidents which represents approximately a 25 percent reduction in accident severity. Table 15 provides various levels of effectiveness for breakaway devices which may be used and the corresponding reduction in cost due to the reduction in severity (ΔC_A) based on 1981 NSC costs. Shaded portions of table 15 are not recommended and may greatly overestimate the effectiveness of breakaway poles. If other than 1981 NSC accident costs are used, refer to the discussion on unit accident costs to compute C_A and ΔC_A for various reductions in accident severity.

Step 11 - Compute Total Accident Benefits (B_T)

Total accident benefits is the sum of benefits due to the reduced number of accidents and reduced accident severity. The total accident benefit is:

$$B_T = B_A + B_S \qquad (15)$$

Table 14. Change in accident costs ΔC_A due to a reduction in accident severity.

Percent Accidents by Severity			Percent Reduction in Injury Plus Fatal Accidents	Accident Cost (C_A)*	Reduction in Accident Cost (ΔC_A)
PDO	I	F			
52.7	46.3	1.0	0	$ 7,007	$ 0
55.1	44.0	0.9	5	6,705	302
57.4	41.7	0.9	10	6,411	596
59.8	39.4	0.8	15	6,118	889
62.2	37.0	0.8	20	5,806	1,201
64.5	34.8	0.7	25	5,512	1,495
66.9	32.4	0.7	30	5,210	1,797
69.3	30.1	0.6	35	4,908	2,099
71.6	27.8	0.6	40	4,614	2,393
74.0	25.5	0.5	45	4,211	2,796
76.4	23.1	0.5	50	4,018	2,989

* Based on 1981 NSC accident costs.

Table 15. Values of cost reduction (ΔC_A) due to various reductions in accident severity from breakaway devices*.

Percent Injury and Fatal Accidents Using Breakaway Devices	Percent Reduction in Injury and Fatal Accidents	Average Cost Per Utility Pole Accident	Differences in Average Accident Cost (ΔC_A)
47.3	0	$7,007	$ 0
44.9	5	6,705	302
42.6	10	6,411	596
40.2	15	6,118	889
37.8	20	5,806	1,201
35.5	25	5,512	1,495
33.1	30	5,210	1,797
30.7	35	4,908	2,099
28.4	40	4,614	2,393
23.7	50	4,018	2,989
18.9	60	3,413	3,594

* Based on 1981 NSC Accident Costs.

Where:

B_T = Total accident benefits per year

B_A = Accident benefits due to reduced accident occurrences per year (Step 9)

B_S = Accident benefits due to reduced accident severity per year (Step 10)

Step 12 - Determine Change in Maintenance Costs (C_M)

The change in maintenance costs is to be calculated on an annual basis for the section. This is computed as follows:

$$C_M = (C_{MB} \times L) - (C_{MA} \times L)$$

Where:

C_M = The change in maintenance costs per year due to the countermeasure.

C_{MB} = The maintenance costs per mile per year before countermeasure installation.

C_{MA} = The maintenance costs per mile per year after countermeasure installation.

L = Section length in miles.

If maintenance costs are unknown, a value of $0 should be used for C_M.

Step 13 - Determine Countermeasure Installation Cost (C_I)

The countermeasure installation cost should be complete and include the cost of removing an old line of poles, purchasing right-of-way (if applicable) and other installation-related costs. If installation costs are unknown, Tables 8 and 9 provide average costs for the countermeasures of undergrounding utility lines and relocating poles, respectively. The costs of relocating poles (table 9) includes the countermeasures of increasing lateral pole offset, increasing pole spacing and eliminating one line of poles where two existed. Both tables provide average dollar values based on area type (urban or rural) and type of utility line. This data was based on responses to a survey of 31 utility companies in 20 states across the United States conducted in 1981 [5].

Average cost data were not available for breakaway devices since the development and testing of such a device is incomplete. However, Mak and Mason [6] estimated retrofitting breakaway poles to cost approximately

$982 per pole. In the absence of additional information, a cost of $1,000 per pole is recommended for breakaway poles, as recommended by Zegeer and Parker [5].

Implementation costs (C_I) should be in the units of dollars per year. Countermeasure installation costs may be given as a cost per mile (C_L), cost per pole (C_P) or a lump sum cost (C_S). These can be converted to an equivalent uniform annual cost per mile by using one of the three following methods.

Method 13-A - If countermeasure costs are given in costs per mile (to be incurred at project inception) the equivalent uniform annual cost (C_I) is:

$$C_I = (C_L) \times (CRF^i{}_n) \times (L) \quad (16)$$

Where:

C_I = The initial construction costs amortized over the entire project period (n years).

C_L = Initial construction costs per mile.

$CRF^i{}_n$ = The capitol recovery factor at interest rate i for a project life of n years (table 16).

L = Section length in miles.

If the values for i and n are unknown, default values of 12 percent for interest rate (i), and 20 years service life (n) can be used. Table 14 is a sample of capital recovery factors for various interest rates and project durations.

Method 13-B - If initial construction costs are provided on a cost per utility pole basis, the countermeasure implementation cost should be calculated as follows:

$$C_I = (C_P) \times (P_L) \times (CRF^i{}_n) \times (L) \quad (17)$$

Where:

C_I = The initial construction costs per mile amortized over the entire project period (n years).

C_P = The initial construction cost per utility pole.

P_L = The number of utility poles per mile. Table 17 can be used to convert pole spacings to the number of utility poles per mile.

Table 16. Capital recovery factors (CRF's) for various service lives (n) and interest rates (i).

YEAR	i=10%	i=12%	i=14%	i=16%
1	1.1000	1.1200	1.1400	1.1600
2	0.5762	0.5917	0.6073	0.6230
3	0.4021	0.4163	0.4307	0.4453
4	0.3155	0.3292	0.3432	0.3574
5	0.2638	0.2774	0.2913	0.3054
6	0.2296	0.2432	0.2572	0.2714
7	0.2054	0.2191	0.2332	0.2476
8	0.1874	0.2013	0.2156	0.2302
9	0.1736	0.1877	0.2022	0.2171
10	0.1627	0.1770	0.1917	0.2069
11	0.1540	0.1684	0.1834	0.1989
12	0.1468	0.1614	0.1767	0.1924
13	0.1408	0.1557	0.1712	0.1872
14	0.1357	0.1509	0.1666	0.1829
15	0.1315	0.1468	0.1628	0.1794
16	0.1278	0.1434	0.1596	0.1764
17	0.1247	0.1405	0.1569	0.1740
18	0.1219	0.1379	0.1546	0.1719
19	0.1195	0.1358	0.1527	0.1701
20	0.1175	0.1339	0.1510	0.1687
21	0.1156	0.1322	0.1495	0.1674
22	0.1140	0.1308	0.1483	0.1664
23	0.1126	0.1296	0.1472	0.1654
24	0.1113	0.1285	0.1463	0.1647
25	0.1102	0.1275	0.1455	0.1640
26	0.1092	0.1267	0.1448	0.1634
27	0.1083	0.1259	0.1442	0.1630
28	0.1075	0.1252	0.1437	0.1625
29	0.1067	0.1247	0.1432	0.1622
30	0.1061	0.1241	0.1428	0.1619
31	0.1055	0.1237	0.1425	0.1616
32	0.1050	0.1233	0.1421	0.1614
33	0.1045	0.1229	0.1419	0.1612
34	0.1041	0.1226	0.1416	0.1610
35	0.1037	0.1223	0.1414	0.1609
36	0.1033	0.1221	0.1413	0.1608
37	0.1030	0.1218	0.1411	0.1607
38	0.1027	0.1216	0.1410	0.1606
39	0.1025	0.1215	0.1409	0.1605
40	0.1023	0.1213	0.1407	0.1604
41	0.1020	0.1212	0.1407	0.1604
42	0.1019	0.1210	0.1406	0.1603
43	0.1017	0.1209	0.1405	0.1603
44	0.1015	0.1208	0.1404	0.1602
45	0.1014	0.1207	0.1404	0.1602
46	0.1013	0.1207	0.1403	0.1602
47	0.1011	0.1206	0.1403	0.1601
48	0.1010	0.1205	0.1403	0.1601
49	0.1009	0.1205	0.1402	0.1601
50	0.1009	0.1204	0.1402	0.1601

Table 17. Conversion of pole spacing to poles per mile*.

Pole Spacing (Feet)	Pole Density (Poles/Mile)
50	106
60	88
70	75
80	66
90	59
100	53
110	48
120	44
130	41
140	38
150	35
175	30
200	26

* Note: This table assumes only one line of utility poles. If two lines of poles exist, the conversion of pole spacing to poles per mile must be done independently for each line of poles and added together to obtain the total number of poles per mile.

1 foot = 0.3 m

1 pole/mile = 0.6 poles/km

CRF^i_n = The Capital Recovery Factor at interest rate i and project service life of n years (table 16).

L = Section length in miles.

Method 13-C - If a single project cost or a lump sum cost is given, the calculation for C_I should be:

$$C_I = (C_S) \times CRF^i_n \qquad (18)$$

Where:

C_I = The initial construction costs amortized over the entire project period (n years).

C_S = Total initial countermeasure cost.

CRF^i_n = The Capital Recovery Factor at interest rate i for a project life of n years (table 16).

Step 14 - Calculate Total Countermeasure Cost (C_T)

$$C_T = C_M + C_I \qquad (19)$$

Where:

C_T = Total project cost amortized over the project life.

C_M = The change in annual maintenance cost (Step 12).

C_I = The initial construction costs amortized over the project period (Step 13).

Step 15 - Calculate the Benefit-to-Cost-Ratio (B/C)

The B/C ratio for the project is the total benefits divided by the total project costs as follows:

$$B/C = \frac{B_T}{C_T} \qquad (20)$$

Where:

B/C = The benefit-to-cost ratio for the countermeasure.

B_T = The total accident benefits per year (Step 11).

C_T = The total countermeasure costs per year (Step 14).

Steps 2 through 10 are repeated for each countermeasure being evaluated. Therefore. if 3 countermeasures are being evaluated, Steps 2 through 15 (work form C) will be completed 3 times. The remainder of the steps will be completed on Worksheet D (figure 19).

Step 16 - Conduct Incremental Benefit-to-Cost Ratio Analysis ($\Delta B/\Delta C$)

The countermeasures should all be reviewed to determine which are cost-effective. If the benefit-cost ratio is greater than 1.0 (or some other minimum value specified by the agency), then the countermeasure should be considered for selection. Be cautious with countermeasures such as breakaway devices whose effectiveness are speculative and have not been field tested. Countermeasures which are feasible and available for implementation should be considered for selection in this step in the analysis.

If only one countermeasure has a B/C ratio greater than 1.0, then this is the alternative which would be selected based on an incremental benefit-cost analysis. If no alternatives have a B/C ratio greater than 1.0, then the do-nothing or existing conditions may be preferable, although projects should also be considered with B/C ratios below 1.0. If two or more alternatives have a benefit-to-cost ratio greater than 1.0, an incremental benefit-to-cost analysis should be conducted to select the most desirable countermeasure.

The incremental benefit-to-cost ratio is used to select countermeasures based on whether extra increments of expenditures are justified for a particular location. The method assumes that the relative merit of a project is measured by its increased benefits (compared to the next lower-priced alternative) divided by its increase in cost (compared to the next lower-priced alternative).

To conduct the incremental benefit-to-cost ratio, first eliminate those alternatives whose B/C ratios are less than or equal to 1.0 or some other minimum value assigned by the agency. Rank the remaining projects in order from the lowest to highest cost (C_T) with the corresponding benefit and cost information as shown below:

Starting with alternative 2 (second lowest total cost - C_T), compare the incremental cost ($C_2 - C_1$) with the incremental benefits ($B_2 - B_1$). If the incremental benefits ($B_2 - B_1$) are greater than the incremental costs ($C_2 - C_1$) or $\Delta B/\Delta C$ is greater than 1.0, then alternative 2 is justified, and alternative 1 should be eliminated from consideration. If the incremental benefits ($B_2 - B_1$) are less than the incremental costs ($C_2 - C_1$) or $\Delta B/\Delta C$ is less than 1.0, then Alternative 1 is justified and Alternative 2 should be eliminated from consideration.

Alternative Ranking	Total Benefits (B_T)	Total Costs (C_T)	Incremental Change In Benefits (ΔB)	Incremental Change In Costs (ΔC)	Comparison	Incremental Benefit-Cost Ratio $\Delta B/\Delta C$
Lowest Cost 1	B_1	C_1	--	--	--	--
2	B_2	C_2	$B_2 - B_1$	$C_2 - C_1$	2-1	$(B_2-B_1)/(C_2-C_1)$
3	B_3	C_3	$B_3 - B_2$	$C_3 - C_2$	3-2	$(B_3-B_2)/(C_3-C_2)$
4	B_4	C_4	$B_4 - B_3$	$C_4 - C_3$	4-3	$(B_4-B_3)/(C_4-C_3)$
Highest Cost 5	B_5	C_5	$B_5 - B_4$	$C_5 - C_4$	5-4	$(B_5-B_4)/(C_5-C_4)$

The alternative justified for further analysis should be compared to alternative 3 and the evaluations of incremental benefit to incremental costs should be made. This procedure should be repeated until only one alternative remains.

Step 17 - Evaluate Available Funding and Other Agency Constraints

Once the optimal alternative has been selected based on the incremental benefit/cost analysis, the agency must determine if it has the funding available to implement the treatment and if project implementation is feasible for the agency. If sufficient revenues are not available, or if political, legal or other constraints prohibit countermeasure selection, this alternative must be eliminated and the next highest rated countermeasure (from the incremental benefit/cost analysis) must be selected and evaluated. This process should be repeated until a countermeasure is selected which meets the funding constraints of the agency.

Step 18 - Record Project Details

The project details of the selected countermeasure should be documented for future reference, such as project planning and implementation and for conducting cost-effectiveness evaluations at other sites. Copies of the work sheets are given in Appendix E.

VI. UPACE COMPUTER PROGRAM

This chapter describes the Utility Pole Accident Countermeasure Evaluation (UPACE) program for analyzing the cost-effectiveness of utility pole accident countermeasures. Two versions of the UPACE program were developed. A main-frame version was developed on an Amdahl 470/V8 computer system and a version was developed for use on a microcomputer operating under the UCSD P-System. The two versions of the program are very similar, with the exception of the machine-dependent operating procedure and commands to execute the programs.

The UPACE program is used as a tool to facilitate the cost-effectiveness analysis of utility pole accident countermeasures. The program undertakes various analyses and provides the information needed for decision making including:

- Traffic projections.
- Consideration of future occupant restraint systems (safety belts and air bags).
- Estimation of utility pole accidents and severity.
- User-defined or default countermeasure analysis.
- Future vehicle downsizing and its effect on accident severity.
- Determination of the influence of roadside objects.
- Economic analysis of alternative countermeasures.
- Comparative analysis of alternative countermeasures.

This chapter briefly describes the structure of the UPACE program, and provides a description of the models utilized, the program inputs, and the reports generated.

Program Overview

The analysis of utility pole accident problems involves a multi-step process as shown in figure 20. The process begins with the systematic review of accident or roadway information data to identify existing or potentially hazardous roadway sections. It is then necessary to compile the data needed to characterize the section from existing records, through field data collection, and/or by data extrapolation. Once the section and its traffic and accident experience are characterized, it is possible to estimate future traffic and accidents. These estimates will reflect the expectations for future trends given that the configuration of utility poles remains the same.

Once the accident problem has been identified, it is necessary to identify countermeasures to decrease the utility pole accident frequency or severity. Each countermeasure will have unique accident reduction potentials, design features, and associated costs and benefits. Once baseline data is collected, and countermeasure alternatives identified the UPACE program can be utilized to perform the analyses. Estimates of the benefits of each countermeasure are determined by the program. Using the benefits and user input costs, the feasibility of a particular countermeasure can then be measured by the application of standard economic principles. The relationship between benefits and costs can then be expressed in terms of a benefit-cost ratio. This process is repeated for each alternative and/or set of alternatives.

Since there may be more than one approach to solving a utility pole accident problem, it becomes necessary to provide a means to compare alternatives. A comparative analysis capability is provided in the form of an incremental benefit-to-cost ratio analysis of feasible alternatives.

The process is repeated for each alternative and/or set of alternatives. The information generated in the analysis represents an important input to the decision-making process. In the project selection process, the economic aspects are considered along with design, construction, and other factors. Often, it becomes necessary to revise the project design or alter the cost inputs of an alternative and re-evaluate the economic viability. Ultimately, this process provides valuable information regarding which alternative should be implemented.

The UPACE program provides a means to undertake all of the steps in the process with the exception of the initial problem identification. The user must input the site characteristics and parameters. The UPACE program operation is depicted by the dashed box shown in figure 20. The program provides a means to facilitate undertaking these steps including the

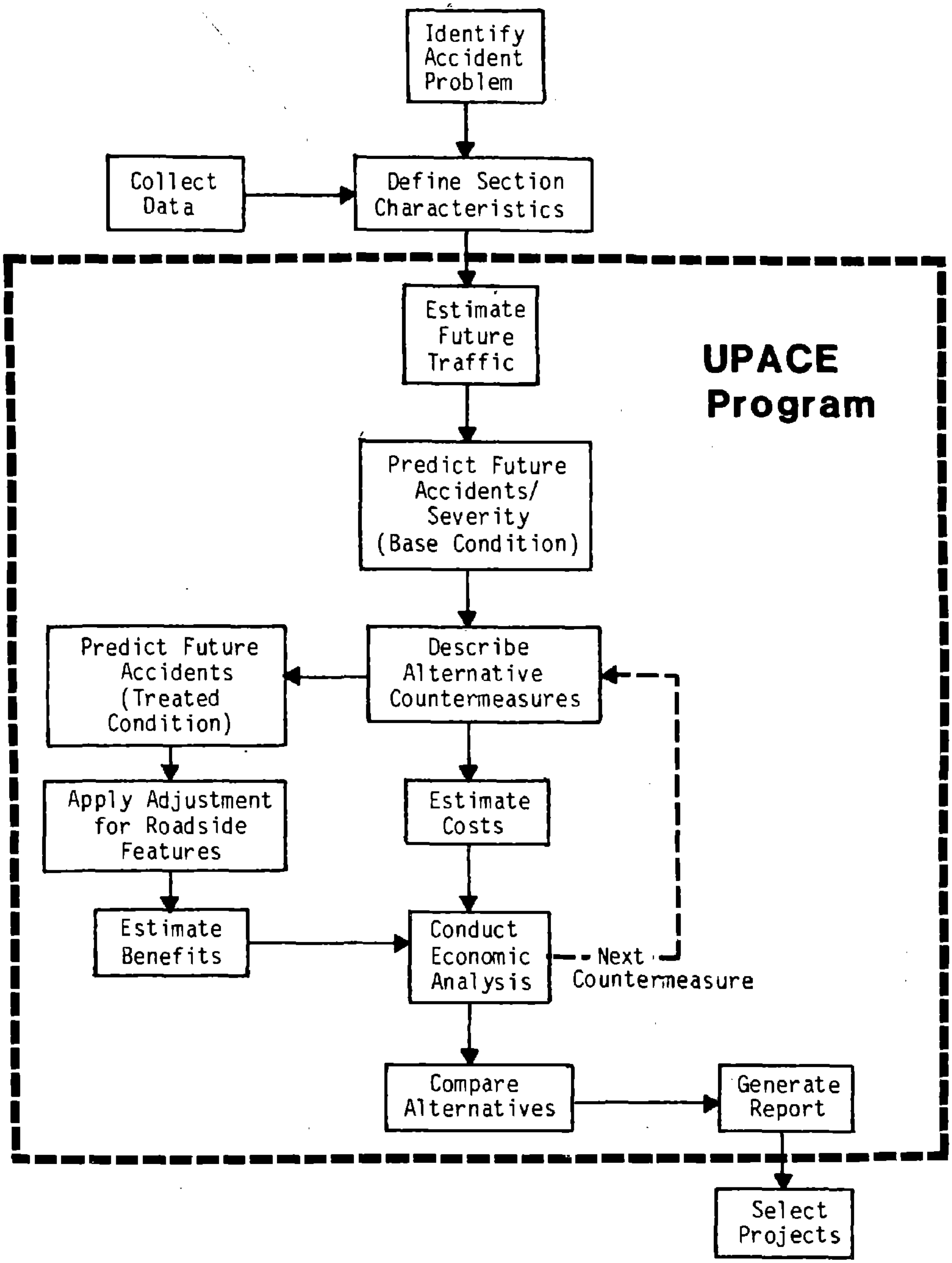


Figure 20. Utility pole countermeasure selection procedure using the UPACE program.

provision of default data and countermeasures. The optional default countermeasures allow the derivation of accident and cost estimates for typical improvement alternatives, where the user chooses not to input a specific alternative. This feature provides flexibility for the users to make "quick first-cut" analyses to ultimately better define feasible alternative treatments.

Program Description

The UPACE program was developed to facilitate the cost-effectiveness analysis of utility pole accident countermeasures. It was designed to provide considerable latitude to the user in the analysis of different roadway, accident, and traffic conditions. The program has built-in default options and values to permit a user to analyze potential countermeasures with limited input. The flexibility also exists for user input of detailed data describing the roadway section, the traffic volumes, the accident experience, and the features of the proposed accident countermeasures. The following sections provide details on the structure, inputs operations, and outputs of the UPACE program.

Program Structure

The UPACE program is structured into several parts each having a particular function. These parts are:

- Processing control (MAIN program)
- Data input and checking
- Traffic projections
- Severity trends analysis
- Roadside features adjustment
- Countermeasure analysis
- Economic analysis
- Comparative analysis of alternative countermeasures

The following paragraphs briefly describe the functions of each of the above parts of the program.

The basic function of the MAIN program is to control the processing of information related to the evaluation of utility pole accident countermeasures. The MAIN program reads the user, section, traffic, and accident data and undertakes the necessary checks and processing of the data for analysis purposes. It initializes internal variables and stores the appropriate default values for subsequent processing. The MAIN program reads information describing each countermeasure to be considered. When accident or countermeasure data are not provided by the user, the program generates default estimates for analysis. The MAIN program sets the analysis parameters, controls the generation of traffic and accident projections, defines the user-input or default countermeasures to be tested, provides an economic analysis of each countermeasure, conducts and evaluates the alternative countermeasures. For each of these major processing steps, the program calls the appropriate subroutines and controls the transfer of information to and from the subprograms.

The UPACE program is designed to estimate future traffic volumes by linear extrapolation, decreasing rate methods, or by direct input of future traffic volumes. The user can input the method and the appropriate parameters, when known, or the program will generate future estimates of traffic volume using default values. Utility pole accident estimates are made using the predictive model developed in previous research [5], unless the user inputs actual utility pole accident data for the section.

The estimates of utility pole accident severity can be adjusted in the severity trends subroutine to reflect the impact of increases in smaller, lighter vehicles in the traffic stream, the increased use of safety belts or occupant restraint systems, and/or other factors. The resulting severity trends factor better reflects the number of fatalities and injuries expected for a given roadway section.

The effectiveness of any countermeasure is determined by comparing the accident frequency and severity projections for the base and improved roadway conditions. The change in the number of accidents, fatalities, and injuries is then translated into dollar amounts (using NSC accident costs) to represent the accident reduction benefit. The user also has the option of inputing other cost values used by an individual agency.

The program provides for an adjustment of the net roadside accident reductions to reflect the influence of roadside conditions on the likelihood of an accident. The model developed by Glennon in previous research relates the ordering of poles, fixed objects, the sideslope, curbs, and the obstructed zone and their relative distances from the roadway to the likelihood of a utility pole accident occurring [15]. The resulting roadside adjustment factor takes into account the net benefit of the countermeasure based on the roadside coverage of fixed objects. The adjustment factor is based on the premise that a utility pole accident involved a run-off-the-road occurrence and that the effect of the countermeasure (i.e., pole relocation or removal) will allow the vehicle either to: (1) recover; (2) rollover on the sideslope; or (3) strike another fixed object. This adjustment results in a larger net accident reduction for a section with a clear roadside than for a section cluttered with other fixed objects such as trees, guardrail, and mailboxes. The difference in expected accidents between the improved and base condition is adjusted by this roadside hazard factor to provide a more accurate indication of countermeasure effectiveness.

Each countermeasure input by the user or selected from the default set of countermeasures is subjected to an economic analysis. In the analysis, the costs and revenues associated with the implementation, operation, and maintenance of the countermeasures are considered. The cost items are translated to equivalent uniform annual cost measures. The benefits to be derived from the reduction of accidents over the life of the countermeasure and any direct revenues are similarly translated to equivalent uniform annual benefits. A benefit-cost ratio is then computed to indicate the viability of each countermeasure. The program is designed to provide considerable flexibility to the user in the economic analysis of countermeasures. The program allows up to 20 separate cost or revenue items to be input for each countermeasure to indicate the various initial, periodic, annual, and terminal costs or revenues which may be associated with a particular countermeasure. This allows for a comprehensive assessment of the fiscal viability of a proposed project. The user, on the other hand, may input only a general cost estimate (or use the default values) to get a quick estimate of the fiscal viability of a project. In either case, the program applies the necessary factors to translate cost or revenue elements to a common time period, computes the equivalent uniform annual values, and determines the associated benefit-cost ratio. A summary of the economic analysis results for each countermeasure is provided.

The program also generates a comparative assessment of alternative countermeasures. When more than one countermeasure has a benefit-cost ratio of 1.0 or greater for a given section of roadway, the program automatically undertakes an incremental benefit-to-cost ratio analysis of the alternatives. The projects are ordered on the basis of their capital costs, and then compared incrementally to each successively higher capital cost alternative. The resulting output provides a means to determine the best alternative.

The MAIN program provides for the output of various data summaries and evaluation reports for use in the assessment process. Further details about the program are provided in the UPACE program documentation.

Program Inputs

The UPACE program requires various inputs indicating the user, the characteristics of the section, traffic volumes, accident experience, and information defining each countermeasure to be considered. The various types of required and optional input data are described in table 18. The items indicated in table 18 with one asterisk are for display purposes and those items denoted with two asterisks are optional inputs, which implies that the program will run without these inputs. The user may opt to utilize the program with other than the default values in the program. The items listed as display values are not necessary for use of the program, but are included to allow a better description of the section.

Program Outputs

The UPACE program produces several types of output reports including:

Table 18. Input data elements for the UPACE program.

User Data

- Name
- Agency

Roadway Section Data

- Road name*
- Section ID number*
- Section location*
- Beginning milepoint
- Ending milepoint
- Width of roadway*
- Posted speed
- Number of through lanes*
- Operation code*
- Shoulder type
- Sideslope
- ROW width*
- Roadside coverage factor
- Roadway alignment*
- Terrain code*
- Area type
- Pavement type*
- Distance to obstructed zone
- Distance to hinge point
- Distance to objects line

Utility Pole Data

- Pole configuration
- Number of unobstructed poles in the section
- Average pole offset
- Pole type coded
- Line type code

Traffic Data

- Base year ADT
- Traffic projections method**
- Traffic growth rate**
- Upper limit on traffic volume**
- Estimated ADT's by year**

Accident Data

- Average annual number of utility pole accidents for the section**
- Percent of accidents involving fatalities**
- Percent of accidents involving injuries**
- Number of persons injured per accident**

Accident/Severity Trend Data

- Severity trend prediction method**
- Severity change rate**
- Severity change year**
- Severity rate after change year**
- Severity change factors**

Economic Analysis Data

- Length of analysis period (years)**
- Interest rate**
- Accident costs**

Countermeasure Data**

- Countermeasure name
- Revised roadside section/utility pole data
- Accident severity reduction factors
- Cost/revenue information

Note: * Data used for display purposes only
** Optional inputs, default values or options will be used if not entered.

- Input Data Checks
- Section Data Summary
- Data Projections Summary
- Countermeasure Effectiveness Summary
- Comparative Analysis Summary

Each of these outputs are described below.

The Input Data Checks Report provide the user with readily understood messages for input data items that are not within acceptable ranges. The input check routine generates an error or warning message for each required input item that fails to meet the program criteria. The program checks all inputs for a given section, aborts the run if error messages have been flagged. Warning messages are printed where data incompatibilities are found in noncritical input items. These warning messages indicate values outside acceptable ranges or the program's actions relative to setting default values. Program execution will continue if only warning messages are detected. A typical data check summary is shown in figure 21.

The Section Data Summary shown in figure 22 is generated for each roadway section analyzed. It summarizes the various input data values related to the roadway, utility pole features, traffic conditions, and accident experience. This report provides a convenient summary of the characteristics of the section being considered for improvement. The accident data summaries provided in this output will reflect actual accident experience, if it is input by the user. If the actual accident data is unavailable, the program predicts an expected number of utility pole accidents per year for the section.

A Data Projections Summary is also provided for the section. This report indicates the predicted traffic volumes, the severity trends factor, the number of utility pole accidents by type, and the expected fatalities and injuries for the duration of the analysis period, as shown in figure 23. This report summarizes the expected accidents for the section for the base or do-nothing condition. The accident values are based upon the results of the accident and traffic volume projections model with adjustments for severity trends.

The UPACE program prepares a Countermeasure Effectiveness Summary for each input or default countermeasure considered for a roadway section. The summary is generated in two parts as shown in figures 24 and 25. The first summary (figure 24) displays the utility pole characteristics for the section before and after the countermeasure is implemented. A before and after comparison of the section and utility pole characteristics is provided to facilitate the assessment of alternative countermeasures.

```
U P A C E  --  UTILITY POLE ACCIDENT COUNTERMEASURES EVALUATION PROGRAM
-----------------------------------------------------------------------

   INPUT DATA CHECK BEGINS

   INPUT DATA CHECK COMPLETED
```

Figure 21. Example data checks summary.

```
U P A C E  --  UTILITY POLE ACCIDENT COUNTERMEASURES EVALUATION PROGRAM
-----------------------------------------------------------------------
                                                          PAGE:    1

   SECTION: ROUTE 1234 (CASE STUDY #1)
   LOCATION: WESTPHALIA
   SECTION ID: 1234                       RUN BY: CHARLES V ZEGEER
                                          AGENCY: GOODELL-GRIVAS, INC.
                                          DATE:   JUN 20, 1984

 SECTION CHARACTERISTICS
 --------------------------------------------------------------------

    SEGMENT

      BEG. MILEPOST:          0.0        END MILEPOST:           2.50
      LENGTH (MILES):         2.50

    ROADWAY

      ROAD ALIGNMENT:        TANGENT    SHOULDER TYPE:          4-8 FEET
      NUMBER OF LANES:             2    RIGHT-OF-WAY WIDTH:      60 FEET
      ROAD WIDTH:           26. FEET    TRAFFIC FLOW:            TWO-WAY
      TERRAIN:                  FLAT    AREA TYPE:                 RURAL
      PAVEMENT:             CONCRETE    ROADSIDE COVERAGE FACTOR:  0.30
      SIDE SLOPE:          FILL  6:1    OBJECTS LINE:            12 FEET
      HINGE LINE:            10 FEET    NON-CLEAR ZONE:          30 FEET

    UTILITY POLES

      POLE CONFIGURATION:   ONE SIDE    POLE TYPE:              WOODEN
      NUMBER OF POLES:           125    POLE USE:            TELEPHONE
      POLE OFFSET:            5 FEET    LINE TYPE:           TELEPHONE

    TRAFFIC

      SPEED LIMIT:           55. MPH    GROWTH FACTOR CODE:        1
      BASE YEAR ADT:      10000. VEH    GROWTH RATE(%):         2.00

    AVERAGE UTILITY POLE ACCIDENTS PER YEAR

      TOTAL ACCIDENTS:         2.52     FATAL ACCIDENTS:    0.03(  1.0%)
      INJURY ACCIDENTS:  1.17( 46.3%)   PROPERTY DAMAGE:    1.33( 52.7%)
      FATALITIES:             0.03      FATALITIES/FATAL ACC.   1.08
      INJURIES:               1.55      INJURIES/FATAL ACC:     0.70
                                        INJURIES/INJURY ACC:    1.31
 --------------------------------------------------------------------
```

Figure 22. Example section data summary.

```
U P A C E  --  UTILITY POLE ACCIDENT COUNTERMEASURES EVALUATION PROGRAM
--------------------------------------------------------------------------
                                                                PAGE:   2

   SECTION: ROUTE 1234 (CASE STUDY #1)
   LOCATION: WESTPHALIA
   SECTION ID: 1234                         RUN BY: CHARLES V ZEGEER
                                            AGENCY: GOODELL-GRIVAS, INC.
                                            DATE:   JUN 20, 1984


  DATA PROJECTIONS SUMMARY FOR SECTION
--------------------------------------------------------------------------
 YEAR   ADT    SEVERITY             ACCIDENTS                    PERSONS
                FACTOR    TOTAL   FATAL  INJURY    PDO      KILLED  INJURED

   1  10000.    1.00      2.52    0.03    1.17    1.33      0.03    1.55
   2  10200.    1.00      2.54    0.03    1.18    1.34      0.03    1.56
   3  10404.    1.00      2.56    0.03    1.18    1.35      0.03    1.57
   4  10612.    1.00      2.58    0.03    1.19    1.36      0.03    1.58
   5  10824.    1.00      2.60    0.03    1.20    1.37      0.03    1.59
   6  11041.    1.00      2.62    0.03    1.21    1.38      0.03    1.61
   7  11262.    1.00      2.64    0.03    1.22    1.39      0.03    1.62
   8  11487.    1.00      2.66    0.03    1.23    1.40      0.03    1.63
   9  11717.    1.00      2.68    0.03    1.24    1.41      0.03    1.65
  10  11951.    1.00      2.70    0.03    1.25    1.43      0.03    1.66
  11  12190.    1.00      2.73    0.03    1.26    1.44      0.03    1.67
  12  12434.    1.00      2.75    0.03    1.27    1.45      0.03    1.69
  13  12682.    1.00      2.77    0.03    1.28    1.46      0.03    1.70
  14  12936.    1.00      2.80    0.03    1.29    1.47      0.03    1.72
  15  13195.    1.00      2.82    0.03    1.31    1.49      0.03    1.73
  16  13459.    1.00      2.85    0.03    1.32    1.50      0.03    1.75
  17  13728.    1.00      2.87    0.03    1.33    1.51      0.03    1.76
  18  14002.    1.00      2.90    0.03    1.34    1.53      0.03    1.78
  19  14282.    1.00      2.92    0.03    1.35    1.54      0.03    1.79
  20  14568.    1.00      2.95    0.03    1.37    1.55      0.03    1.81
  21  14859.    1.00      2.98    0.03    1.38    1.57      0.03    1.83
  22  15157.    1.00      3.00    0.03    1.39    1.58      0.03    1.84
  23  15460.    1.00      3.03    0.03    1.40    1.60      0.03    1.86
  24  15769.    1.00      3.06    0.03    1.42    1.61      0.03    1.88
  25  16084.    1.00      3.09    0.03    1.43    1.63      0.03    1.90

               TOTALS    69.62    0.70   32.23   36.69      0.75   42.71
--------------------------------------------------------------------------
```

Figure 23. Example section data projections summary - base conditions.

```
U P A C E  --  UTILITY POLE ACCIDENT COUNTERMEASURES EVALUATION PROGRAM

                                                               PAGE:    3

     SECTION: ROUTE 1234 (CASE STUDY #1)
     LOCATION: WESTPHALIA
     SECTION ID: 1234                          RUN BY: CHARLES V ZEGEER
                                               AGENCY: GOODELL-GRIVAS, INC.
                                               DATE:   JUN 20, 1984

       ALTERNATIVE  1 -- POLE RELOCATION TO 20 FEET


    SUMMARY OF CHANGES
                                          BEFORE     AFTER

       POLE DENSITY                          50         50 POLES/MILE
       POLE OFFSET                            5         20 FEET
       POLE COVERAGE FACTOR                0.32       0.32
       ROADSIDE COVERAGE FACTOR            0.30       0.30
       SIDE SLOPE                      FILL 6:1   FILL 6:1
       NON-CLEAR ZONE                        30         30 FEET
       OBJECTS LINE                          12         12 FEET
       HINGE LINE                            10         10 FEET
       POLE TYPE                              1          1


    EXPECTED UTILITY POLE ACCIDENTS AFTER IMPROVEMENT

  YEAR    SEVERITY              ACCIDENTS                        PERSONS
           FACTOR     TOTAL   FATAL   INJURY     PDO       KILLED   INJURED

    1       1.00       1.04    0.01    0.48     0.55        0.01     0.64
    2       1.00       1.05    0.01    0.49     0.55        0.01     0.64
    3       1.00       1.06    0.01    0.49     0.56        0.01     0.65
    4       1.00       1.07    0.01    0.49     0.56        0.01     0.65
    5       1.00       1.07    0.01    0.50     0.57        0.01     0.66
    6       1.00       1.08    0.01    0.50     0.57        0.01     0.66
    7       1.00       1.09    0.01    0.51     0.58        0.01     0.67
    8       1.00       1.10    0.01    0.51     0.58        0.01     0.68
    9       1.00       1.11    0.01    0.51     0.59        0.01     0.68
   10       1.00       1.12    0.01    0.52     0.59        0.01     0.69
   11       1.00       1.13    0.01    0.52     0.60        0.01     0.69
   12       1.00       1.14    0.01    0.53     0.60        0.01     0.70
   13       1.00       1.15    0.01    0.53     0.61        0.01     0.71
   14       1.00       1.16    0.01    0.54     0.61        0.01     0.71
   15       1.00       1.17    0.01    0.54     0.62        0.01     0.72
   16       1.00       1.18    0.01    0.55     0.62        0.01     0.73
   17       1.00       1.19    0.01    0.55     0.63        0.01     0.73
   18       1.00       1.20    0.01    0.56     0.63        0.01     0.74
   19       1.00       1.22    0.01    0.56     0.64        0.01     0.75
   20       1.00       1.23    0.01    0.57     0.65        0.01     0.75
   21       1.00       1.24    0.01    0.57     0.65        0.01     0.76
   22       1.00       1.25    0.01    0.58     0.66        0.01     0.77
   23       1.00       1.26    0.01    0.59     0.67        0.01     0.78
   24       1.00       1.28    0.01    0.59     0.67        0.01     0.78
   25       1.00       1.29    0.01    0.60     0.68        0.01     0.79

          TOTALS      28.89    0.29   13.38    15.23        0.31    17.73

     NOTE:
      1. ACCIDENT/SEVERITY PROJECTIONS NOT ADJUSTED FOR ROADSIDE FEATURES.
```

Figure 24. Example countermeasure effectiveness summary - accident projections.

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U P A C E  --  UTILITY POLE ACCIDENT COUNTERMEASURES EVALUATION PROGRAM

                                                                 PAGE:   5

 SECTION: ROUTE 1234 (CASE STUDY #1)
 LOCATION: WESTPHALIA
 SECTION ID: 1234                            RUN BY: CHARLES V ZEGEER
                                             AGENCY: GOODELL-GRIVAS, INC.
                                             DATE:   JUN 20, 1984


ALTERNATIVE  1 -- POLE RELOCATION TO 20 FEET


ANALYSIS PARAMETERS

     PROJECT LIFE:            25 YEARS        COST/FATALITY      $   190000.
     INTEREST RATE:          10.00 %          COST/INJURY        $     7200.
     FATAL ACC. REDUCTION FACTOR:      1.00   COST/PDO ACCIDENT  $     1020.
     INJURY ACC. REDUCTION FACTOR:     1.00
     PDO ACCIDENT REDUCTION FACTOR:    1.00

ACCIDENT REDUCTION DATA

     ROADSIDE ADJUSTMENT FACTOR:        0.695

     TOTAL ROADSIDE ACCIDENTS REDUCED:  28.31
     NET PDO ACCIDENTS REDUCED:         14.92
     NET FATALITIES PREVENTED:           0.31
     NET INJURIES PREVENTED:            17.37

     TOTAL ACCIDENT SAVINGS ($):       69389.44

COUNTERMEASURE DATA

   ITEM    DESCRIPTION            TYPE          START    END     AMOUNT
                                                YEAR     YEAR      ($)

   1  POLE RELOCATION COSTS    INITIAL COST       0      25     50000.00

ECONOMIC ANALYSIS RESULTS

     EQUIVALENT UNIFORM ANNUAL COST:        5508.40
     EQUIVALENT UNIFORM ANNUAL BENEFIT:     7644.50
     BENEFIT-COST RATIO:                       1.388
```

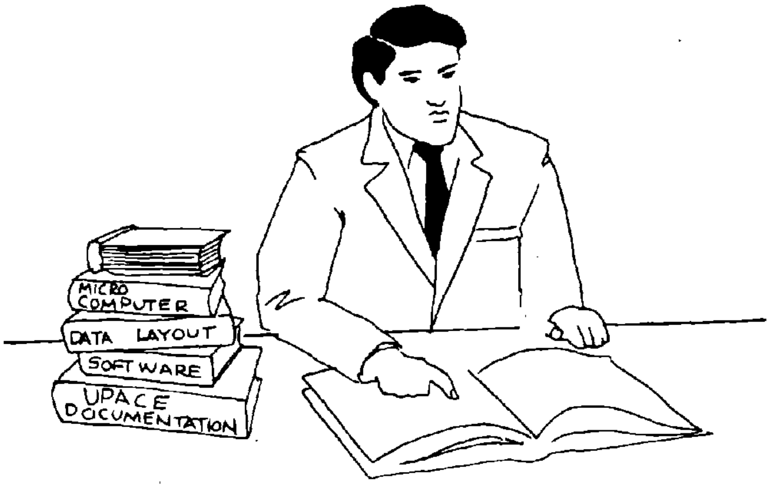
Figure 25. Example countermeasure effectiveness summary - cost-effectiveness analysis.

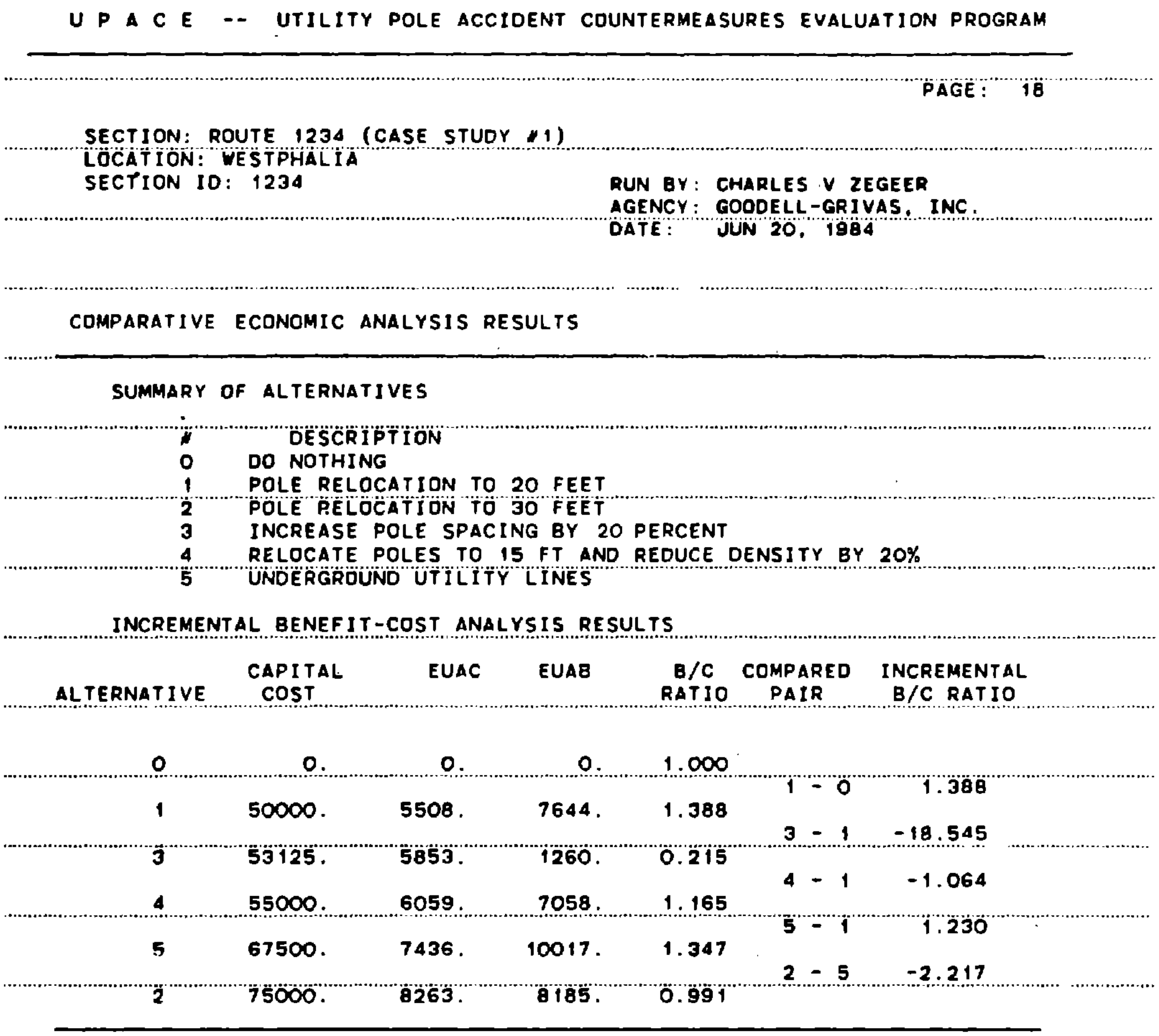
The lower portion of the first countermeasure effectiveness report summarizes the expected utility pole accident and severity data after the improvement. This summary reflects the accident reduction predicted by the model, and the influence of the severity trend factor, but does not reflect the adjustment for roadside coverage of fixed objects.

The second countermeasure effectiveness report focuses on the results of the economic analysis for the countermeasure as shown in figure 25. This report summarizes the economic analysis parameters, indicates the predicted accident reductions (modified using the roadside adjustment factor), lists the cost or revenue items included in the analysis, and gives the equivalent annual costs, benefits, and benefit-cost (B/C) ratio for the alternative countermeasures. This report provides a convenient means to review and analyze the assumptions used in the economic assessment of alternative countermeasure.

The last report generated is a Comparative Analysis Summary for all countermeasures for a section, based an incremental benefit-to-cost analysis. Figure 26 shows this comparative report which summarizes the alternatives analyzed, the capital cost, the equivalent uniform annual benefits, the equivalent uniform annual costs, and the individual and incremental B/C ratios.

More detailed information on the program output can be found in the UPACE program documentation. Case studies utilizing the UPACE program are provided in Chapter XI along with comparisons to evaluations using the manual procedure.





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U P A C E  --  UTILITY POLE ACCIDENT COUNTERMEASURES EVALUATION PROGRAM

                                                                 PAGE:   18

   SECTION: ROUTE 1234 (CASE STUDY #1)
   LOCATION: WESTPHALIA
   SECTION ID: 1234                          RUN BY: CHARLES V ZEGEER
                                             AGENCY: GOODELL-GRIVAS, INC.
                                             DATE:    JUN 20, 1984


  COMPARATIVE ECONOMIC ANALYSIS RESULTS

     SUMMARY OF ALTERNATIVES

              #    DESCRIPTION
              0    DO NOTHING
              1    POLE RELOCATION TO 20 FEET
              2    POLE RELOCATION TO 30 FEET
              3    INCREASE POLE SPACING BY 20 PERCENT
              4    RELOCATE POLES TO 15 FT AND REDUCE DENSITY BY 20%
              5    UNDERGROUND UTILITY LINES

     INCREMENTAL BENEFIT-COST ANALYSIS RESULTS

                  CAPITAL      EUAC       EUAB       B/C   COMPARED  INCREMENTAL
 ALTERNATIVE       COST                             RATIO    PAIR     B/C RATIO


       0            0.          0.         0.      1.000
                                                             1 - 0       1.388
       1         50000.       5508.      7644.     1.388
                                                             3 - 1     -18.545
       3         53125.       5853.      1260.     0.215
                                                             4 - 1      -1.064
       4         55000.       6059.      7058.     1.165
                                                             5 - 1       1.230
       5         67500.       7436.     10017.     1.347
                                                             2 - 5      -2.217
       2         75000.       8263.      8185.     0.991
```
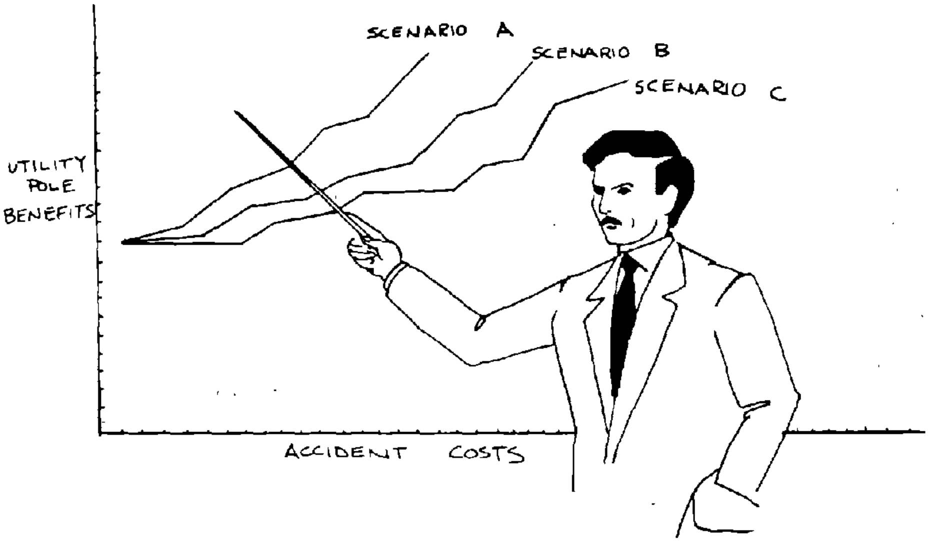

Figure 26. Example comparative analysis summary.

VII. SENSITIVITY OF VARIOUS FACTORS



The use of the cost-effectiveness procedures requires numerous user inputs, as discussed in Chapters III and IV. The purpose of this chapter is to describe the sensitivity of the analysis results to each of these input variables. This is important so that the user is aware of which input variables have the greatest effect on the analysis results and, therefore, require the most precision.

Several of the inputs are only descriptive variables which are not directly used in the analysis, but are useful only in describing site characteristics to the user. These descriptive variables include:

- Location description (road name, etc.)
- Shoulder width
- Right-of-way width
- Roadway width
- Pavement type (concrete or asphalt)
- Number of lanes
- Operation (one-way, or two-way)
- Roadway alignment (tangent, gentle curve, and sharp curve)
- Terrain (flat, rolling, and hilly)
- Pole type (wood, metal, or concrete)

It is recognized that these factors could have an effect on utility pole accidents, but they were not found to be of significant importance in the accident analysis [5]. For example, very few hilly sections were found where utility poles follow parallel to the roadway, since utility lines are commonly placed in a straight line down the mountain to minimize the length of utility lines and the number of poles placed. Section-by-section accident analysis also did not allow for developing accident relationships for specific poles or by degree of curve.

The sensitivity of other variables is discussed below in terms of their influence on:

- Utility pole accidents,
- Roadside adjustment factor (which has a direct influence on countermeasure effectiveness and accident benefits),
- Countermeasure costs, and
- Economic analysis.

Variables Affecting Utility Pole Accidents

Several variables for the cost-effectiveness procedures have an effect on expected utility pole accidents, which ultimately influences accident benefits due to various countermeasures. The three most important variables were pole offset, pole density and traffic volume. The sensitivity of these three variables along with the consideration of pole configuration are discussed below.

Pole Offset

A summary is given in table 17 of the expected utility pole accidents due to the combined effect of pole offset and pole density on utility pole accidents. The sensitivity to pole offset can be seen by comparing utility pole accidents in vertical columns for any given combination of pole density and traffic volume. For example, for an ADT of 10,000 and pole density of 60 poles per mile (38 poles/km), utility pole accidents vary from 2.01 per mile per year (1.26/km/year) for a 2-foot (0.6-m) offset to 0.36 (0.23/km/year) for a 30-foot (9-m) offset, a difference of 1.65 accidents per mile per year. Of this difference, 1.35 of it (82 percent) occurs between 2 and 12 feet (0.6 and 3.6 m) offsets. Thus, it can be readily seen that pole offset has a large effect on utility pole accidents, particularly for offsets of about 2 to 10 feet (0.6 to 3 m). For higher levels of traffic volume or pole densities, the sensitivity further increases. For example, for an ADT of 60,000 and pole density of 60 poles per mile (38 poles/km), utility pole accidents vary from 5.26 per mile per year (3.29/km/year) at 2-foot (0.6-m) offsets to 1.00 (0.63/km/year) for 30-foot (9-m) offsets, a difference of 4.26 accidents per mile per year (2.66 accidents/km/year). An illustration is given in figure 27 of the utility pole accident frequency as a function of pole offset as determined in the research study by Zegeer and Parker [5]. The curve was adjusted for traffic volume and pole density.

Table 19. Predicted utility pole accident experience for various levels of traffic volume, pole density and pole offset.

ADT LEVEL 1000.

POLE OFFSET (FEET)	POLE DENSITY (POLES/MILE)										
	20.	25.	30.	35.	40.	45.	50.	55.	60.	65.	70.
2.	0.49	0.61	0.72	0.84	0.96	1.08	1.19	1.31	1.43	1.54	1.66
5.	0.27	0.33	0.40	0.47	0.54	0.60	0.67	0.74	0.81	0.87	0.94
7.	0.21	0.26	0.32	0.37	0.43	0.48	0.54	0.60	0.65	0.71	0.76
10.	0.16	0.21	0.25	0.29	0.34	0.38	0.43	0.47	0.52	0.56	0.61
12.	0.14	0.18	0.22	0.26	0.30	0.34	0.38	0.42	0.46	0.50	0.54
15.	0.12	0.15	0.19	0.22	0.26	0.29	0.33	0.36	0.40	0.43	0.47
20.	0.09	0.12	0.15	0.18	0.21	0.24	0.27	0.30	0.33	0.36	0.39
25.	0.08	0.10	0.13	0.15	0.18	0.20	0.23	0.25	0.28	0.31	0.33
30.	0.06	0.09	0.11	0.13	0.16	0.18	0.20	0.22	0.25	0.27	0.29

ADT LEVEL 2000.

POLE OFFSET (FEET)	POLE DENSITY (POLES/MILE)										
	20.	25.	30.	35.	40.	45.	50.	55.	60.	65.	70.
2.	0.56	0.67	0.79	0.91	1.02	1.14	1.26	1.37	1.49	1.61	1.72
5.	0.30	0.37	0.44	0.51	0.57	0.64	0.71	0.78	0.84	0.91	0.98
7.	0.24	0.29	0.35	0.41	0.46	0.52	0.57	0.63	0.68	0.74	0.79
10.	0.19	0.23	0.27	0.32	0.36	0.41	0.45	0.50	0.54	0.59	0.63
12.	0.16	0.20	0.24	0.28	0.32	0.36	0.40	0.44	0.48	0.52	0.56
15.	0.14	0.17	0.21	0.24	0.28	0.31	0.35	0.38	0.42	0.45	0.49
20.	0.11	0.14	0.17	0.20	0.23	0.25	0.28	0.31	0.34	0.37	0.40
25.	0.09	0.12	0.14	0.17	0.19	0.22	0.24	0.27	0.29	0.32	0.35
30.	0.08	0.10	0.12	0.14	0.17	0.19	0.21	0.24	0.26	0.28	0.31

ADT LEVEL 3000.

POLE OFFSET (FEET)	POLE DENSITY (POLES/MILE)										
	20.	25.	30.	35.	40.	45.	50.	55.	60.	65.	70.
2.	0.62	0.74	0.85	0.97	1.09	1.20	1.32	1.44	1.56	1.67	1.79
5.	0.34	0.41	0.48	0.54	0.61	0.68	0.75	0.81	0.88	0.95	1.01
7.	0.27	0.33	0.38	0.44	0.49	0.55	0.60	0.66	0.71	0.77	0.82
10.	0.21	0.25	0.30	0.34	0.39	0.43	0.48	0.52	0.57	0.61	0.66
12.	0.18	0.22	0.26	0.30	0.34	0.38	0.42	0.46	0.50	0.54	0.58
15.	0.16	0.19	0.23	0.26	0.30	0.33	0.37	0.40	0.43	0.47	0.50
20.	0.12	0.15	0.18	0.21	0.24	0.27	0.30	0.33	0.36	0.39	0.42
25.	0.10	0.13	0.15	0.18	0.21	0.23	0.26	0.28	0.31	0.33	0.36
30.	0.09	0.11	0.13	0.16	0.18	0.20	0.23	0.25	0.27	0.30	0.32

ADT LEVEL 4000.

POLE OFFSET (FEET)	POLE DENSITY (POLES/MILE)										
	20.	25.	30.	35.	40.	45.	50.	55.	60.	65.	70.
2.	0.69	0.80	0.92	1.04	1.15	1.27	1.39	1.50	1.62	1.74	1.85
5.	0.38	0.45	0.51	0.58	0.65	0.72	0.78	0.85	0.92	0.98	1.05
7.	0.30	0.36	0.41	0.47	0.52	0.58	0.63	0.69	0.74	0.80	0.85
10.	0.23	0.28	0.32	0.37	0.41	0.46	0.50	0.55	0.59	0.64	0.68
12.	0.21	0.25	0.29	0.33	0.37	0.41	0.45	0.49	0.53	0.57	0.61
15.	0.18	0.21	0.24	0.28	0.31	0.35	0.38	0.42	0.45	0.49	0.52
20.	0.14	0.17	0.20	0.23	0.26	0.29	0.32	0.35	0.38	0.41	0.43
25.	0.12	0.14	0.17	0.19	0.22	0.25	0.27	0.30	0.32	0.35	0.37
30.	0.10	0.12	0.15	0.17	0.19	0.22	0.24	0.26	0.29	0.31	0.33

ADT LEVEL 5000.

POLE OFFSET (FEET)	POLE DENSITY (POLES/MILE)										
	20.	25.	30.	35.	40.	45.	50.	55.	60.	65.	70.
2.	0.75	0.87	0.98	1.10	1.22	1.33	1.45	1.57	1.69	1.80	1.92
5.	0.42	0.48	0.55	0.62	0.69	0.75	0.82	0.89	0.95	1.02	1.09
7.	0.33	0.39	0.44	0.50	0.55	0.61	0.66	0.72	0.77	0.83	0.88
10.	0.26	0.30	0.35	0.39	0.44	0.48	0.53	0.57	0.62	0.66	0.70
12.	0.23	0.27	0.31	0.35	0.39	0.43	0.47	0.51	0.55	0.59	0.63
15.	0.19	0.23	0.26	0.30	0.33	0.37	0.40	0.44	0.47	0.51	0.54
20.	0.16	0.19	0.22	0.25	0.27	0.30	0.33	0.36	0.39	0.42	0.45
25.	0.13	0.16	0.18	0.21	0.23	0.26	0.29	0.31	0.34	0.36	0.39
30.	0.11	0.14	0.16	0.18	0.21	0.23	0.25	0.28	0.30	0.32	0.34

ADT LEVEL 10000.

POLE OFFSET (FEET)	POLE DENSITY (POLES/MILE)										
	20.	25.	30.	35.	40.	45.	50.	55.	60.	65.	70.
2.	1.07	1.19	1.31	1.43	1.54	1.66	1.78	1.89	2.01	2.13	2.24
5.	0.60	0.67	0.74	0.80	0.87	0.94	1.01	1.07	1.14	1.21	1.28
7.	0.48	0.54	0.59	0.65	0.71	0.76	0.82	0.87	0.93	0.98	1.04
10.	0.38	0.43	0.47	0.52	0.56	0.61	0.65	0.69	0.74	0.78	0.83
12.	0.34	0.38	0.42	0.46	0.50	0.54	0.58	0.62	0.66	0.70	0.74
15.	0.29	0.33	0.36	0.40	0.43	0.47	0.50	0.54	0.57	0.61	0.64
20.	0.24	0.27	0.30	0.33	0.36	0.39	0.41	0.44	0.47	0.50	0.53
25.	0.20	0.23	0.25	0.28	0.31	0.33	0.36	0.38	0.41	0.43	0.46
30.	0.18	0.20	0.22	0.25	0.27	0.29	0.32	0.34	0.36	0.39	0.41

Table 19. Predicted utility pole accident experience for various levels of traffic volume, pole density and pole offset (Continued).

ADT LEVEL 20000.

POLE OFFSET (FEET)	POLE DENSITY (POLES/MILE) 20.	25.	30.	35.	40.	45.	50.	55.	60.	65.	70.
2.	.72	1.84	1.96	2.07	2.19	2.31	2.43	2.54	2.66	2.78	2.89
5	0.98	1.04	1.11	1.18	1.25	1.31	1.38	1.45	1.52	1.58	1.65
7.	0.79	0.85	0.90	0.96	1.01	1.07	1.12	1.18	1.23	1.29	1.34
10.	0.63	0.67	0.72	0.76	0.81	0.85	0.90	0.94	0.99	1.03	1.08
12.	0.56	0.60	0.64	0.68	0.72	0.76	0.80	0.84	0.88	0.92	0.96
15.	0.49	0.52	0.55	0.59	0.62	0.66	0.69	0.73	0.76	0.80	0.83
20.	0.40	0.43	0.46	0.49	0.52	0.55	0.58	0.61	0.64	0.67	0.70
25.	0.35	0.37	0.40	0.42	0.45	0.47	0.50	0.53	0.55	0.58	0.60
30.	0.31	0.33	0.35	0.37	0.40	0.42	0.44	0.47	0.49	0.51	0.54

ADT LEVEL 30000.

POLE OFFSET (FEET)	POLE DENSITY (POLES/MILE) 20.	25.	30.	35.	40.	45.	50.	55.	60.	65.	70.
2.	2.37	2.49	2.61	2.72	2.84	2.96	3.07	3.19	3.31	3.43	3.54
5.	1.35	1.42	1.49	1.55	1.62	1.69	1.76	1.82	1.89	1.96	2.03
7.	1.10	1.15	1.21	1.26	1.32	1.37	1.43	1.48	1.54	1.59	1.65
10.	0.88	0.92	0.97	1.01	1.06	1.10	1.14	1.19	1.23	1.28	1.32
12.	0.78	0.82	0.86	0.90	0.94	0.98	1.02	1.06	1.10	1.14	1.18
15.	0.68	0.71	0.75	0.78	0.82	0.85	0.89	0.92	0.96	0.99	1.03
20.	0.56	0.59	0.62	0.65	0.68	0.71	0.74	0.77	0.80	0.83	0.86
25.	0.49	0.51	0.54	0.57	0.59	0.62	0.64	0.67	0.69	0.72	0.75
30.	0.43	0.46	0.48	0.50	0.53	0.55	0.57	0.59	0.62	0.64	0.66

ADT LEVEL 40000.

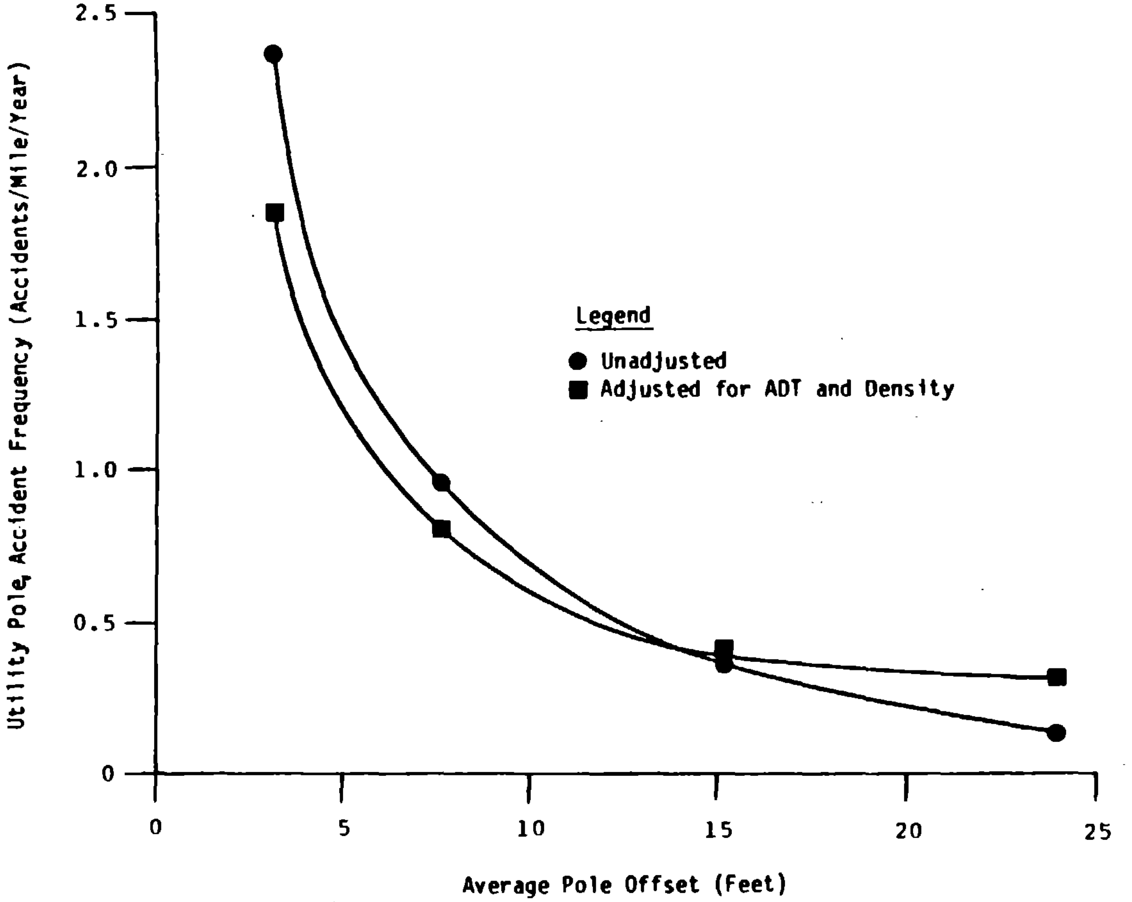
POLE OFFSET (FEET)	POLE DENSITY (POLES/MILE) 20.	25.	30.	35.	40.	45.	50.	55.	60.	65.	70.
2.	3.02	3.14	3.26	3.37	3.49	3.61	3.72	3.84	3.96	4.07	4.19
5.	1.73	1.79	1.86	1.93	2.00	2.06	2.13	2.20	2.27	2.33	2.40
7.	1.40	1.46	1.51	1.57	1.62	1.68	1.73	1.79	1.84	1.90	1.95
10.	1.12	1.17	1.21	1.26	1.30	1.35	1.39	1.44	1.48	1.53	1.57
12.	1.00	1.04	1.08	1.12	1.16	1.20	1.24	1.28	1.32	1.36	1.40
15.	0.87	0.91	0.94	0.98	1.01	1.05	1.08	1.12	1.15	1.19	1.22
20.	0.73	0.76	0.79	0.82	0.85	0.87	0.90	0.93	0.96	0.99	1.02
25.	0.63	0.66	0.68	0.71	0.73	0.76	0.79	0.81	0.84	0.86	0.89
30.	0.56	0.58	0.61	0.63	0.65	0.68	0.70	0.72	0.75	0.77	0.79

ADT LEVEL 50000.

POLE OFFSET (FEET)	POLE DENSITY (POLES/MILE) 20.	25.	30.	35.	40.	45.	50.	55.	60.	65.	70.
2.	3.67	3.79	3.90	4.02	4.14	4.26	4.37	4.49	4.61	4.72	4.84
5.	2.10	2.17	2.24	2.30	2.37	2.44	2.51	2.57	2.64	2.71	2.78
7.	1.71	1.76	1.82	1.87	1.93	1.98	2.04	2.09	2.15	2.21	2.26
10.	1.37	1.42	1.46	1.51	1.55	1.59	1.64	1.68	1.73	1.77	1.82
12.	1.23	1.27	1.30	1.34	1.38	1.42	1.46	1.50	1.54	1.58	1.62
15.	1.07	1.10	1.14	1.17	1.21	1.24	1.28	1.31	1.35	1.38	1.42
20.	0.89	0.92	0.95	0.98	1.01	1.04	1.07	1.10	1.13	1.15	1.18
25.	0.77	0.80	0.83	0.85	0.88	0.90	0.93	0.95	0.98	1.00	1.03
30.	0.69	0.71	0.74	0.76	0.78	0.80	0.83	0.85	0.87	0.90	0.92

ADT LEVEL 60000.

POLE OFFSET (FEET)	POLE DENSITY (POLES/MILE) 20.	25.	30.	35.	40.	45.	50.	55.	60.	65.	70.
2.	4.32	4.44	4.55	4.67	4.79	4.90	5.02	5.14	5.26	5.37	5.49
5.	2.48	2.54	2.61	2.68	2.75	2.81	2.88	2.95	3.01	3.08	3.15
7.	2.02	2.07	2.13	2.18	2.24	2.29	2.35	2.40	2.46	2.51	2.57
10.	1.62	1.66	1.71	1.75	1.80	1.84	1.89	1.93	1.97	2.02	2.06
12.	1.45	1.49	1.53	1.57	1.61	1.65	1.69	1.73	1.77	1.81	1.85
15.	1.26	1.30	1.33	1.36	1.40	1.43	1.47	1.50	1.54	1.57	1.61
20.	1.05	1.08	1.11	1.14	1.17	1.20	1.23	1.26	1.29	1.32	1.35
25.	0.92	0.94	0.97	0.99	1.02	1.04	1.07	1.10	1.12	1.15	1.17
30.	0.82	0.84	0.86	0.89	0.91	0.93	0.96	0.98	1.00	1.02	1.05



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

Figure 27. Relationship between utility pole accident frequency and pole offset.

Source: Reference 5

Pole Density

The effect of pole density on utility pole accidents is illustrated in figure 28 [5]. Although utility pole accidents increase with increasing pole density, the effect is not as great as with pole offset. Notice that the curve is relatively smooth, which indicates a nearly straight line relationship between pole density and accidents.

This can also be seen in table 19, by comparing numbers horizontally for different levels of traffic volume and pole offset. For example, on roads with daily traffic volumes of 10,000 and pole offsets of 2 feet (0.3 m), utility pole accidents range from 1.07 (accidents/mile/year) for 20 poles per mile (13 poles/km) to 2.24 for 70 poles per mile (44 poles/km). An increase of 10 poles per mile (6 poles/km) results in a change of approximately 0.24 accidents per mile per year. For daily traffic volumes of 10,000 and 30-foot (9-m) offsets, utility pole accidents range from 0.18 accidents per mile per year for 20 poles per mile (13 poles/km) to 0.41 for 70 poles per mile (44 poles/km). In this case, an increase of approximately 0.04 accidents per mile per year occurs for every increase of 10 poles per mile (6 poles/km). This suggests that greater accident reduction may be obtained due to increasing pole offset than due to reducing pole density.

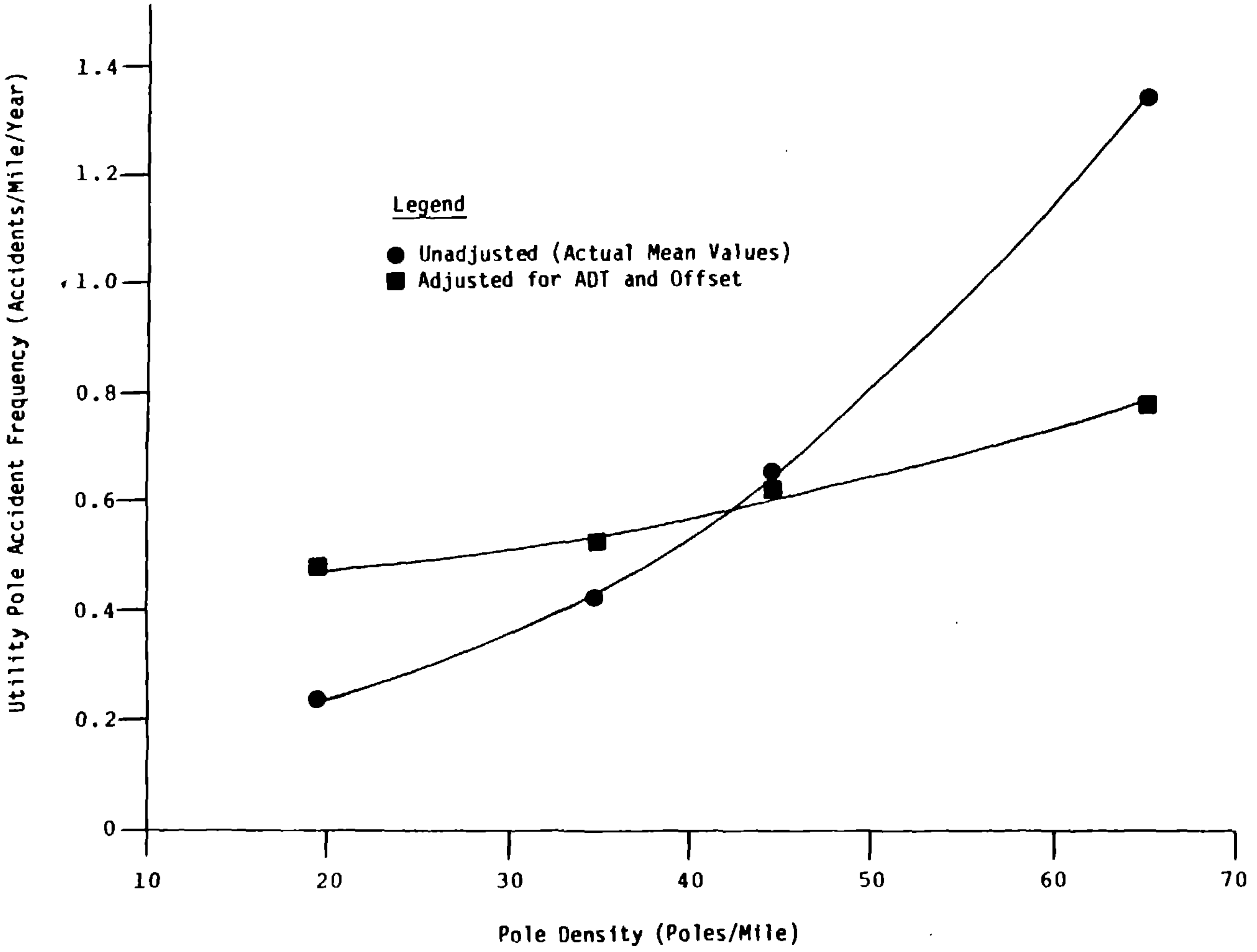
Traffic Volume

The effect of traffic volume on utility pole accidents can also be determined from table 20. By selecting a fixed level of pole offset and pole density, accident experience can be found for increasing levels of traffic volume. For example, assume pole offsets of 5 feet (1.5 m) and a pole density of 50 poles per mile (31 poles/km). The utility pole accident experience corresponding to various traffic volume levels is shown in table 18. Note that an increase of approximately 0.04 utility pole accidents per mile per year is expected for each increase of 1,000 vehicles per day.

Similar comparisons can also be made by making such comparisons for other combinations of pole density and offset. For example, with pole offsets of 2 feet (0.6 m) and 70 poles per mile (44 poles/km), utility pole accidents increase by approximately 0.06 per mile per year with each increase of 1,000 vehicles per day (i.e., 1.66 for 1,000 ADT, 1.72 for 2,000 ADT, 1.79 for 3,000 ADT, 1.85 for 4,000 ADT, etc.). For 20 poles per mile (13 poles/km) and 30-foot (9-m) offsets, the increase is approximately 0.01 to 0.02 accidents per mile per year for each increase of 1,000 vehicles per day (i.e., 0.06 at 1,000 ADT, 0.08 at 2,000 ADT, 0.09 at 3,000 ADT, etc.).

Pole Configuration

This variable indicates how poles are configured with respect to the roadway, such as:



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

Figure 28. Relationship between utility pole accident frequency and pole density.

Source: Reference 5

Table 20. Relationship between traffic volume and utility pole accident experience.

Average Daily Traffic Volume (ADT)	Utility Pole Acc/Mi/Yr	Change in ADT	Change in Utility Pole Acc/Mi/Yr*	Change in Acc/Mi/Yr Per 1,000 Veh/Day*
1,000	0.67			
		1,000	0.04	0.04
2,000	0.71			
		1,000	0.04	0.04
3,000	0.75			
		1,000	0.04	0.04
4,000	0.78			
		1,000	0.04	0.04
5,000	0.82			
		5,000	0.19	0.038
10,000	1.01			
		10,000	0.37	0.037
20,000	1.38			
		10,000	0.38	0.038
30,000	1.76			
		10,000	0.37	0.037
40,000	2.13			
		10,000	0.38	0.038
50,000	2.51			
		10,000	0.37	0.037
60,000	2.88			

Note: 1 mile = 1.6 km

* The values assume a roadway with 50 poles per mile (31 poles/km) and 5-foot (1.5 m) average pole offsets.

- Utility poles on one side of road only
- Utility poles on boths sides
- Utility poles in median only
- Utility poles on one side and median
- Utility poles on both sides and median

The cost-effectiveness procedure discussed in this manual only applies to the first two situations, that is, poles on one or both sides of the roadway. Roadway situations with utility poles in the median cannot be handled with these procedures, since an insufficient sample of these types of sections were found for use in the previous research study [5].

Variables Affecting the Roadside Adjustment Factor (H_R)

The roadside adjustment factor is computed for each roadway section to account for the possible increase in other types of run-off-road accidents which may occur as a result of relocating utility poles or undergrounding utility lines. This roadside adjustment factor is a value ranging from 0 to 1.0, which is multiplied by the expected utility pole accident reduction factor to produce an approximation of the net reduction in total roadside accidents. Thus, a roadside adjustment factor of 0 (representing a roadside cluttered with fixed objects) would indicate that no accidents would be reduced from a given countermeasure. In other words, the reduction in utility pole accidents would be offset by an increase in other fixed-object accidents. This may occur when a line of utility poles lies directly in front of a store wall or dense forest, so that relocating poles would have no effect on overall accidents. For most real-world situations, the roadside adjustment factor would range between approximately 0.3 and 0.8.

The roadside adjustment factor is computed as a function of the following variables:

- Percent coverage of fixed objects
- Sideslope
- Distance to the non-clear zone
- Distance to the hinge line

The following is a discussion of the sensitivity of each of these factors in terms of roadside adjustment factor.

Percent Coverage of Fixed-Objects (C_F)

For a 200-foot (60-m) section, the presence of 7 or more fixed objects represents 100 percent coverage, which would result in a roadside adjustment factor of near 0. A range of 0 to 7 fixed objects in a 200-foot (60-m) section would correspond to a roadside adjustment factor of 0 (no benefits from the countermeasure) to 1.0 (full benefits from the countermeasure). Thus, the analysis results are highly sensitive to the coverage of fixed objects.

This effect can be illustrated by considering the range of roadside adjustment factors for various levels of fixed-object coverage and various countermeasures. As shown in table 21, roadside adjustment factors are given for fixed-object coverage of 10 to 90 percent for increasing pole offsets (pole relocation projects), reducing pole density, and for projects involving undergrounding utility lines. For pole relocation of 5 to 15 feet (1.5 to 4.5 m), roadside adjustment factors range from 0.917 (10 percent roadside coverage factor) to 0.655 (90 percent coverage factor). For undergrounding or reducing pole density, the roadside adjustment factors range from 0.711 to 0.222. This indicates that the roadside adjustment factor, and thus the accident benefits, are highly sensitive to the roadside coverage of fixed objects.

Table 21. Sensitivity of the roadside adjustment factor (H_R) to the coverage of fixed-objects (C_F).

Percent Coverage of Fixed Obstacles	Roadside Adjustment Factors for Various Countermeasures*					
	Relocation of Utility Poles				Reduce Pole Density	Underground Utility Lines
	5 to 15 Feet	5 to 20 Feet	5 to 25 Feet	5 to 30 Feet		
10	0.917	0.879	0.864	0.857	0.711	0.711
35	0.835	0.741	0.703	0.684	0.558	0.558
50	0.786	0.657	0.606	0.581	0.466	0.466
65	0.737	0.574	0.509	0.477	0.374	0.374
90	0.655	0.435	0.347	0.305	0.222	0.222

*Values assume an obstructed zone at 30 feet, a hinge line at 10 feet, 50 utility poles per mile, and sideslopes of 6:1 and 4:1, initial pole offset of 5 feet, poles on one side and a rural area type.

Note: 1 foot = 0.3 m
1 pole/mile = 0.6 poles/km
1 mile = 1.6 km

Sideslope

The effect of sideslope on the roadside adjustment factor is illustrated in table 22. For a pole relocation project of 5 to 15 feet (1.5 to 4.5 m), the roadside adjustment factor ranges between 0.850 (6:1 cut slope) to 0.585 (2:1 cut slope). For undergrounding projects, the roadside adjustment factor ranges from 0.571 to 0.335, for cut slopes of 6:1 and 2:1, respectively. In conclusion, it is clear that roadside adjustment factor is sensitive to sideslope, although it is more sensitive to the roadside coverage factor for most types of projects. In areas with curbs (usually urban areas), the side slope is not used in calculating the roadside adjustment factor.

Table 22. Sensitivity of the roadside adjustment factor (H_R) to sideslope.

Slideslope		Roadside Adjustment Factors for Various Countermeasures*					
		Relocation of Utility Poles				Reduce Pole Density	Underground Utility Lines
Fill	Cut	5 to 15 Feet	5 to 20 Feet	5 to 25 Feet	5 to 30 Feet		
10:1	6:1	0.850	0.758	0.721	0.703	0.571	0.571
8:1	5:1	0.835	0.741	0.703	0.684	0.558	0.558
6:1	4:1	0.778	0.671	0.629	0.609	0.506	0.506
4:1	3:1	0.729	0.614	0.568	0.545	0.463	0.463
3:1	2:1	0.585	0.441	0.384	0.356	0.335	0.335

*Values assume a 35 percent fixed-object coverage, a hinge line at 10 feet, a non-clear zone at 30 feet, 50 utility poles per mile, initial pole offsets of 5 feet, poles on one side and rural area type.

Note: 1 foot = 0.3 m
1 pole/mile = 0.6 poles/km
1 mile = 1.6 km

Distance to the Obstructed Zone

The sensitivity of roadside adjustment factor to the location of an obstructed zone is shown in table 23. For a pole relocation project of 5 to 15 meet (1.5 to 4.5 m) the roadside adjustment factor is 0-.507 for a 10-foot (3 m) distance to an obstructed zone, and increases to 0.835 for a 30-foot (9 m) clear zone. The sensitivity (difference in roadside adjustment factors) decreases for larger increases in pole offset, and for undergrounding and reducing pole density. For example, for undergrounding projects, roadside adjustment factors vary from 0.507 to 0.588. Thus, the location of an obstructed zone affects the roadside adjustment factor, but not as much as fixed object coverage.

Table 23. Sensitivity of the roadside adjust factor (H_R) to the location of the obstructed zone.

Distance to the Non-Clear Zone (Feet)	Roadside Adjustment Factors for Various Countermeasures*					
	Relocation of Utility Poles				Reduce Pole Density	Underground Utility Lines
	5 to 15 Feet	5 to 20 Feet	5 to 25 Feet	5 to 30 Feet		
10	0.507	0.507	0.507	0.507	0.507	0.507
15	0.835	0.430	0.430	0.430	0.430	0.430
20	0.835	0.741	0.480	0.480	0.480	0.480
25	0.835	0.741	0.703	0.524	0.524	0.524
30	0.835	0.741	0.703	0.684	0.558	0.558

*Values assume a 35 percent fixed-object coverage, a hinge line at 10 feet, 50 poles per mile, sideslopes of 6:1 and 4:1, initial pole offsets of 5 feet, pole density of 50 poles per mile, rural area type and poles located on one side.

Note: 1 foot = 0.3 m
1 pole/mile = 0.6 poles/km
1 mile = 1.6 km

Location of the Hinge Line

The roadside adjustment factors generated for different hinge line distances are shown in table 24. For pole relocation projects of 5 to 15 feet (1.5 to 4.5 m), the roadside adjustment factors vary from 0.835 representing a 10-foot (3-m) hinge line to 0.874 representing a 30-foot (9-m) hinge line. For undergrounding projects, the roadside adjustment factor varies from 0.558 to 0.592, which is also a small difference (i.e., a differential of only about 0.04 in each case). Thus, hinge line has very little effect on the roadside adjustment factor.

Table 24. Sensitivity of the roadside adjustment factor (H_R) to the location of the hinge line.

Location of the Hinge Line (Feet)	Roadside Adjustment Factors for Various Countermeasures*					
	Relocation of Utility Poles				Reduce Pole Density	Underground Utility Lines
	5 to 15 Feet	5 to 20 Feet	5 to 25 Feet	5 to 30 Feet		
10	0.835	0.741	0.703	0.684	0.558	0.558
15	0.874	0.764	0.720	0.699	0.568	0.568
20	0.874	0.787	0.737	0.713	0.577	0.577
25	0.874	0.787	0.752	0.725	0.586	0.586
30	0.874	0.787	0.752	0.735	0.592	0.592

*Values assume a 35 percent fixed-object coverage, an obstructed zone at 30 feet, 50 poles per mile, and sideslopes of 6:1 and 4:1, 5-foot initial pole offset, poles on one side, and rural areas.

Note: 1 foot = 0.3 m
1 pole/mile = 0.6 poles/km
1 mile = 1.6 km

Variables Affecting Countermeasure Costs

The costs of various countermeasures represent an important input into the cost-effectiveness procedure. The countermeasure costs are highly site specific and, for every section the benefit-cost ratio is directly impacted by the countermeasure cost, which is the denominator. Many factors are known to affect countermeasure costs, including:

- Cost of Labor
- Type of soil (rocky, sand, etc.)
- Type of pole
- Right-of-way (ROW) width
- Line type and uses of the utility line
- The type of construction practice (i.e., direct bury or conduit).
- Level of urbanization
- Location of other utilities
- Indirect project costs
- Change in maintenance costs.

If additional ROW purchase is needed as part of a pole relocation project, the user must estimate this cost and add it as an input. The line uses (i.e., telephone, electric distribution, or transmission, etc.) and type ($\geq$ 69 KV, 3 phase; < 69 KV, one phase, etc.) are input by the user and are the basis for the selection of a default countermeasure cost value, in the event that the user does not provide a cost estimate. These default cost values were given previously in tables 10 and 11 for buried line and pole relocation projects, respectively. The default values should only be used to provide an approximate estimate of cost effectiveness. Site specific costs should be used whenever possible.

Other Variables

In addition to the variables discussed above, several others may also affect the results of the economic analysis, including:

- Project service life
- Interest rate
- Severity and cost of utility pole accidents
- Traffic growth rate

The following is a discussion of each of these factors in terms of their effect on the cost-effectiveness results.

Expected Project Life and Interest Rate

These two factors may be discussed in terms of their combined effect on expected accident benefits (and annual project related costs). In general, a countermeasure may be expected to last a minimum of 15 years, and 30-years is often used as a maximum time limit for purposes of economic analysis. Interest rates are commonly used ranging between about 10 percent and 16 percent.

Various capital recovery factors (CRF) are given in table 16, which illustrates the effect of changing service life and interst rates. For a 10 percent interest rate, capital recovery factors range from 0.1315 for a 15-year life to 0.1061 for a 30-year project life, a ratio of 0.1315/0.1061 = 1.24. At a 16 percent interest rate, this ratio (15 versus 30-year period) is 0.1794/0.1619 = 1.108. Thus, service life of 15 to

30 years has an effect on annualized initial project costs, ranging from about 11 percent to 24 percent (for initial rates of up to 16 percent).

The effect of interest rate can be determined by comparing capital recovery factors for a constant service life. For example, for a 15-year service life, the capital recovery factors range from 0.1315 for a 10 percent interest rate to 0.1794 for a 16 percent interest rate, a ratio of 0.1794/0.1315 = 1.36. For a 30 year service life, the ratio is 0.1619/0.1061 = 1.53. Thus, using a 16 percent interest rate could result in accident benefits of 36 percent to 53 percent higher, compared to using a 10 percent interest rate. Thus, it is safe to conclude that initial project costs are more sensitive to interest rates than to project service life (within the expected range of values).

Severity and Cost of Utility Pole Accidents

The severity of utility pole accidents is reflected by the distribution of injury, fatal, and property damage only accidents. The severity issue enters into the cost-effectiveness procedure in two different ways. First, the average injury and fatal accidents represent 47.3 percent of utility pole accidents. Using 1981 NSC accident costs and determining the average number of injuries and fatalities per utility pole accident, results in an average accident cost of $7,007. Using these NSC accident costs and reducing the average severity of utility pole accidents by 5 percent (44.9 percent injury plus fatal accidents) would result in benefits of approximately $409 per accident. Various agencies also use their own costs per accident. Some base these costs on the number of people injured and killed (i.e., NSC) and some are based on the number of fatal and injury accidents (i.e., some State's direct costs).

It is best to use an average severity of utility pole accidents and not a site-specific severity. This is because a fatal accident is a random occurrence, and one or more random fatal accidents (or fatalities) at a site could inappropriately be used to justify almost any countermeasure. The 1981 NSC accident costs are $190,000 per fatality, $7,200 per injury and $1,020 per property damage only accident. Therefore, a fatality is 26.4 times more expensive than an injury and 186.3 times more expensive than a noninjury accident. Using the NSC cost method, a utility pole accident with 5-occupants resulting in 2 fatalities and 3 injuries would result in a cost of $401,600. If safety belt usage (for example) would have prevented the fatalities and injuries in that single accident, the accident cost would be $1,020 representing a reduction of about 99.7 percent of the cost.

Another use of severity data involves the use of various types of breakaway pole devices. A summary is given in table 25 of the effect of various severity changes on accident cost. For a 30 percent reduction in injury and fatal accidents, the average cost per accident would drop from

Table 25. Sensitivity of accident costs due to reduction in accident severity based on 1981 NSC accident costs.

Percent Injury and Fatal Accidents Using Breakaway Devices	Percent Reduction in Injury and Fatal Accidents	Average Cost Per Utility Pole Accident	Differences in Average Accident Cost (ΔC_A)	Percent Reduction in Cost per Accident
47.3	0	$7,007	$ 0	0.0
44.9	5	6,705	302	4.3
42.6	10	6,411	596	8.5
40.2	15	6,118	889	12.7
37.8	20	5,806	1,201	17.1
35.5	25	5,512	1,495	21.3
33.1	30	5,210	1,797	25.6
30.7	35	4,908	2,099	30.0
28.4	40	4,614	2,393	34.1
23.7	50	4,018	2,989	42.7
18.9	60	3,413	3,594	51.3

$7,007 to $5,201, resulting in a 25.6 percent decrease ($1,797 difference) in cost per accident. A 60 percent decrease in injury and fatal accidents would result in a decrease of $3,594 or 51 percent. From the table, it is clear that the percent decrease in cost per accident is slightly less than the percent reduction in injury plus fatal accidents. However, note that a 50 percent decrease in cost per accident would result in a 50 percent reduction in accident costs (assuming all other factors remain constant). Thus, accident severity can have a large impact on the accident benefit, depending on the effectiveness of the breakaway pole.

Traffic Growth Rate

The traffic growth rates are user inputs of the expected degree of traffic growth (or decrease) expected over the project life. Values of adjustment factors are shown in table 13 for various service lives and growth rates. Assuming a 20 year service life, adjustment factors range from 0.70 (5 percent decrease in volume per year) to 3.86 (10 percent growth in volume per year).

For a roadway with a daily traffic volume of 1,000, a doubling of volume to 2,000 would result in an increase in utility pole accidents of between 0.02 to 0.06 per mile per year (0.01 - 0.04 accidents/km/year). At a daily traffic volume of 10,000, a doubling of volume would result in an increase in utility pole accidents of between 0.13 and 0.65 per mile per year (0.08 - 0.41 accidents/km/year). However, a doubling of traffic volume may not be likely for many moderate to high volume roadway sections, in light of practical capacity constraints. Thus, except where major traffic increases are expected at existing high volume roadways (i.e., greater than a 50 percent increase of volume on roads with daily traffic volumes above 10,000) the traffic growth rate will not have a major impact on utility pole accident experience.

Summary of Sensitivity Analysis

Based on the previous discussion of the sensitivity of various data inputs, the user should be aware of which data inputs are most critical in terms of their impact on the cost-effectiveness results. In summary, the following input variables were found to be of primary importance (i.e., have the most effect on the analysis results):

- Actual accident experience on the section (if given)
- Pole offset, particularly within 10 feet (3 m) of the road
- Traffic volume of the roadway
- Sideslope, particularly for sideslopes steeper than 4 to 1
- Coverage factor of fixed-objects (roadside coverage factor)
- Countermeasure cost (including right-of-way acquisition costs)
- Severity of utility pole accidents and accident costs
- Distance to the non-clear zone.

The following input variables were found to be of moderate importance to the analysis results:

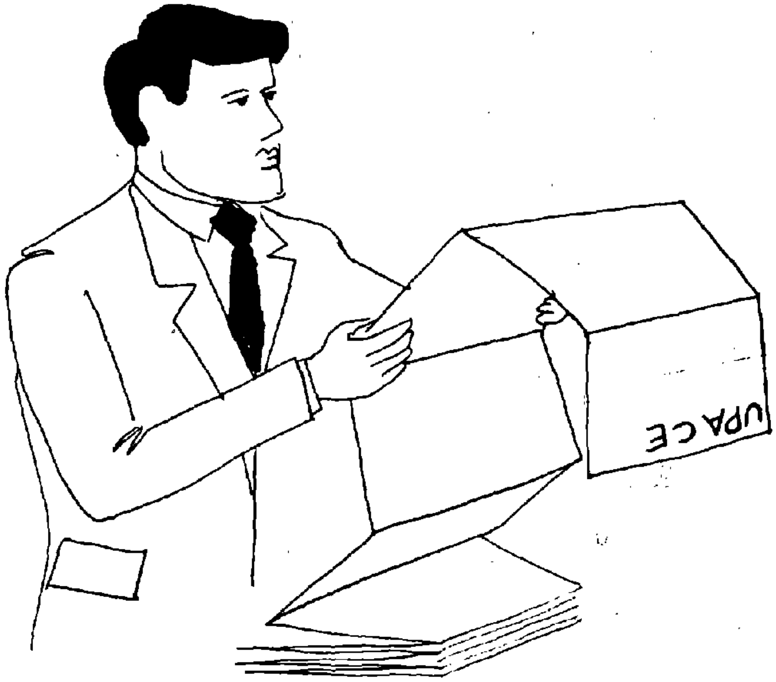
- Interest rate
- Pole density
- Project service life
- Traffic growth rate

Particular care should be taken to insure the accuracy of the variables in the first two groups.

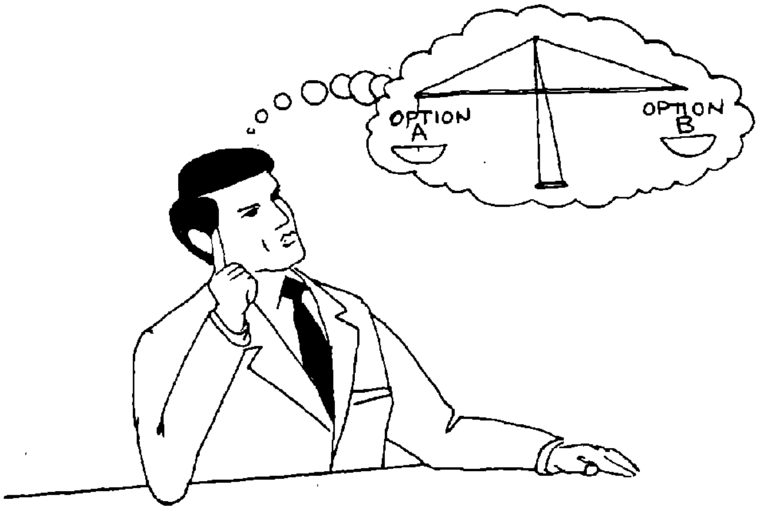
Factors found to have lesser effect on the economic analysis include:

- Configuration of utility poles (one side or two sides)
- Location of the hinge line
- Roadside width
- Pavement type
- Number of lanes
- Operation (one-way or two-way)
- Roadside alignment
- Terrain

The first two factors have a marginal effect on the economic analysis, while the last six variables are used for display purposes only.



VIII. ESTABLISHING PROJECT PRIORITIES



If two or more candidate countermeasures are under consideration for a specific highway section, a decision must be made on which countermeasure will result in the optimal safety benefits per dollar spent. Various procedures which are available to establish priorities for implementation are discussed by Zegeer in the FHWA User's Manual on "Highway Safety Improvement Program" [17] and include the following:

- Procedure 1 - Simple Ranking of Projects (based on benefit-cost ratio, net benefits, rate-of return, etc.)
- Procedure 2 - Incremental Benefit-to-Cost Ratio
- Procedure 3 - Dynamic Programming
- Procedure 4 - Integer Programming

Priorities for implementation should be based on considerations such as available funding, project costs, and expected accident benefits for each countermeasure. The four methods listed above include many of these conditions. Each method is discussed below.

Procedure 1 - Simple Ranking of Projects

This procedure involves ranking project alternatives from best to worst based on benefit-cost ratio, net benefit, rate of return, time of return, or other economic method. Details on each of these methods may be found in numerous other texts.

Of these economic measures, any one of them are appropriate for determining the economic feasibility of a given project (i.e., the B/C ratio is 2.3, the net benefit is $120,000, the rate of return is 22 percent per year, etc.). However, when comparing two or more alternatives, the simple ranking of projects often does not give the optimal results. For example, at a highway section, four options being considered for a utility pole accident problem are: Option A - pole relocation to 20 feet (6 m); Option B - pole relocation to 30 feet (9 m); Option C - multiple pole use; and Option D - underground utility lines. Consider the benefits and costs of each option:

Option	Present Worth Costs	Present Worth Benefits	B/C Ratio
A	100,000	125,000	1.25
B	150,000	170,000	1.13
C	80,000	88,000	1.10
D	200,000	230,000	1.15

In this example, the priority of alternatives based on the simple benefit-cost ratio method would be A, D, B and C. It should be noted that a priority ranking based on the simple B/C ratio will usually result in selecting the lower-cost options, while the simple net benefit method usually results in selecting the higher cost options. However, as mentioned previously simple ranking of projects is not considered appropriate. The optimal solution can be found using the incremental benefit-cost ratio method, as discussed below.

Procedure 2 - Incremental Benefit-to-Cost Ratio Method

This method can be used to determine whether extra increments of cost (i.e.,underground lines as opposed to pole relocation) are justified for a particular location or for considering improvements at two or more locations. The method assumes that the relative merit of a project is measured by its change in benefits and costs, compared to the next lower-cost alternative.

The steps for using the incremental benefit-to-cost ratio method are given below, as discussed in the "Highway Safety Improvement Program" manual [18]:

1. Determine the benefits, costs, and the benefit-to-cost ratio for each improvement.

2. List the improvements with a B/C ratio greater than 1 (or some other minimum value) in order of increasing cost.

3. Calculate the incremental B/C ratio of the second lowest-cost improvement compared to the first.

4. Continue in order of increasing costs, to calculate the incremental B/C ratio for each improvement compared to the next lower cost improvement.

5. Stop when the incremental B/C ratio is less than 1.0.

To illustrate the use of this method, consider the example given previously (with options ordered from lowest to highest cost):

Option	PW of Costs	PW of Benefits	B/C Ratio	Comparison of Options	Δ Benefits	Δ Costs	ΔB/ΔC
C	80,000	88,000	1.10				
				C and A	37,000	20,000	1.85
A	100,000	125,000	1.25				
				A and B	45,000	50,000	0.90
B	150,000	170,000	1.13				
				A and D	105,000	100,000	1.05
D	200,000	230,000	1.15				

From this example, Option A is preferred to Option C (ΔB/ΔC = 1.85), and Option C would be excluded from consideration. Option A is also preferred to option B (ΔB/ΔC = 0.90), since spending an additional $50,000 for Option B would yield only $45,000 of additional benefits. Then a comparison of Option A with Option D will result in an incremental cost increase of $200,000 - $100,000 = $100,000, and an increase in benefits of $230,000 - $125,000 = $105,000. Thus, the ΔB/ΔC = 1.05, so Option D (undergrounding) is the optimal solution based on incremental benefits and costs. This solution would, of course, be subject to funding availability, political considerations, environmental constraints, etc.

Procedures 3 and 4 - Dynamic and Integer Programming

Other, more sophisticated techniques are also available for use in establishing project priorities. Dynamic programming and integer programming are two of these options which were recommended in a 1979 FHWA report by McFarland et al. [18] for use by highway agencies for setting priorities for their highway safety programs.

These two techniques are particularly useful when simultaneously considering numerous alternatives at up to several hundred locations. For consideration of numerous alternatives at a given site, the incremental benefit-cost ratio method is adequate. However, if the user wishes for utility pole accident countermeasures to compete with many other project types for available funding, while considering numerous constraints, then dynamic and integer programming may be worthy of serious consideration.

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APPENDIX A - DEVELOPMENT OF ROADSIDE ADJUSTMENT FACTORS FOR USE IN ASSESSING COUNTERMEASURE EFFECTIVENESS

As discussed in the text, the effectiveness of pole relocation, undergrounding, or multiple pole use is heavily influenced by the general characteristics of the roadside. Most roadside conditions have other fixed objects and curbs or sideslopes, so the net reduction in roadside accidents will be less than the reduction in utility pole accidents. For example, when utility poles are removed, the out-of-control vehicles that would have resulted in a utility pole accident may instead have: (1) no collision at all (the vehicle may recover), (2) hit some other fixed object, or (3) roll over down the sideslope.

For any given roadside configuration, a hazard model such as the one developed by Glennon in NCHRP Report 148 can be used to estimate roadside adjustment factors. The adjustment factors can theoretically transform predicted accident reductions for utility pole countermeasures into net roadside accident reductions. The hazard equation and illustration are given in figure 29, as described by Glennon [1].

Roadside Formulation

For a one-mile (1.6-km) section of roadway, the NCHRP model can be simplified for a non-contiguous roadside obstacle (with a constant sideslope and with no fixed objects) to:

$$H = E_f \cdot S \cdot P\,[Y \geq s] \tag{21}$$

where:

H = Hazard index, number of fatal and nonfatal injury accidents/year

$P\,[Y \geq s]$ = The probability that the lateral encroachment (Y) of a vehicle equals or exceeds the lateral distance (s) of the obstacle from the roadway edge.

E_f = The frequency of encroachments, in number of encroachments per mile (1.6 km) per year

S = A measure of the severity of accidents

But the results of NCHRP Report 247 indicate that this formulation overpredicts the roadside hazard by factors ranging from 2 to 8 depending on the magnitude of roadside slopes and the coverage of fixed objects. In analyzing these results, insights have been gained regarding an apparent flaw in the NCHRP 148 formulation. For example, not every vehicle that encounters a 6:1 fill-slope will have an accident (reported or otherwise), yet the formulation assumes that every encounter guarantees an accident. Therefore, a more appropriate formulation of the simplified model presented above is:

$$H = \frac{E_f S}{5{,}280}\left[l \int_{s}^{\infty} f(y)\,dy + \int_{l}^{l+d\csc\theta}\int_{s+(x-l)\cos\theta\sin\theta}^{\infty} f(y)\,dy\,dx + \int_{l+d\csc\theta}^{l+d\csc\theta+w\cot\theta}\int_{s+d\cos\theta+(x-l-d\sec\theta)\tan\theta}^{\infty} f(y)\,dy\,dx \right]$$

in which

E_f = encroachment frequency, number of encroachments per mile per year;

S = severity index [previously defined as $P(I/C)$], number of fatal and nonfatal injury accidents per total accidents;

l = longitudinal length of the obstacle, feet;

w = lateral width of the obstacle, feet;

s = lateral placement of the obstacle, feet;

d = width of the vehicle, feet;

θ = angle of encroachment, degrees;

x = longitudinal distance from the farthest downstream encroachment point to the encroachment point of reference, feet; and

$f(y)$ = percentile distribution of lateral displacements of encroaching vehicles.

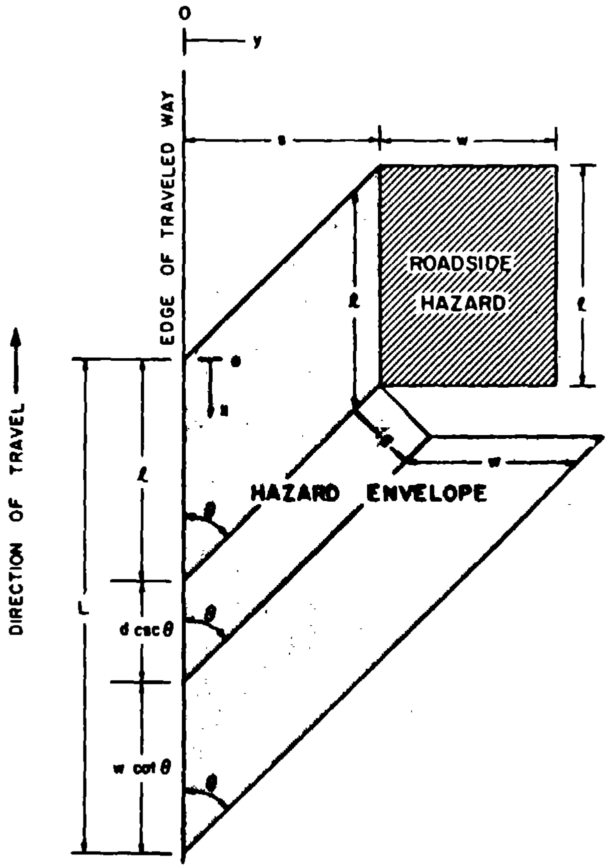

Figure 29. The roadside hazard equation and a schematic illustration of a roadside obstacle and its relationship to an encroaching vehicle.

Source: Reference 2

$$H = E_f \cdot S \cdot R_1 \cdot P\,[Y \geq s] \qquad (22)$$

Where: R_1 = the reporting level of roadside encounters with the obstacle, Reported Accidents/Encounter.

In order to estimate adjustment factors that will transform the predicted utility pole accident reductions into net roadside accident reductions, it is more appropriate to look at conditional probability that any accident (including PDO's) will occur, given that a roadside encroachment has occurred. This conditional probability, P_I, is expressed in its most general form as:

$$P_I = R_1 \cdot P\,[Y \geq s] \qquad (23)$$

Note that E_f (encroachment frequency) is NOT included in this equation. However, because of the nature of roadside accidents with several contiguous accident producing features, the application of the model to specific roadside configurations and utility pole accident countermeasures is exceedingly more complex than the general application described above. The model has 16 basic forms depending on the order that each of five possible contiguous features are encountered. These features include utility poles, other fixed objects, curbs, sideslopes, and what will be generalized as the nonclear zone. The nonclear zone is that area from about 20 to 30 feet (6 to 10 m) from the roadway where there is some nominal level of hazard presented by steeper side-slopes, nonclear trees and foliage, rocks, fences, walls, etc.

Using the basic form of the model to account for the additive contributions of various roadside features, requires one other consideration, that of the coverage factors for utility poles and other fixed objects. The 16 different roadside cases are as follows:

Roadside Feature Order
(from edge of road outward)

Roadside Cases	1st	2nd	3rd	4th
1	U.P.	F.O.	Slope	NCZ
2	U.P.	Slope	F.O.	NCZ
3	U.P.	Slope	NCZ	--
4	F.O.	U.P.	Slope	NCZ
5	F.O.	Slope	U.P.	NCZ
6	F.O.	Slope	NCZ	U.P.
7	Slope	U.P.	F.O.	NCZ
8	Slope	F.O.	U.P.	NCZ
9	Slope	U.P.	NCZ	--
10	Slope	F.O.	NCZ	--
11	Slope	NCZ	U.P.	--
12	Curb	U.P.	F.O.	NCZ
13	Curb	F.O.	U.P.	NCZ
14	Curb	U.P.	NCZ	--
15	Curb	F.O.	NCZ	--
16	Curb	NCZ	U.P.	--

Where:

U.P. = Utility Pole
F.O. = Fixed Object
Slope= Side Slope
NCZ = Nonclear Zone

To explain the 16 cases, consider a roadside with the following characteristics:

- A row of utility poles 4 feet (1.2 m) away from the roadway edge.
- A line of light poles an average of 10 feet (3.0 m) from the roadway edge.
- A sideslope break at 12 feet (3.7 m) from the roadway edge.
- A forest of trees beginning at 20 feet (6.1 m) from the roadway edge.

This roadside situation would correspond to roadside case Number 1 (i.e., first utility pole, then fixed objects, then slope, then non-clear zone).

The equations for each of these cases are given below, where C is the coverage factor, R is the reporting level factor, L is the lateral placement in feet (0.3 m), U is the subscript for utility pole, F is the subscript for fixed object, S is the subscript for side slope, N is the subscript for the nonclear zone, and K is the subscript for curb. The reporting level is the estimated percent of fixed object accidents which are reported, since not all collisions are reportable.

Case 1

$$\begin{aligned} P_I = {} & (C_U)(R_U)P[Y \geq L_U]+(C_F)(1-C_U)(R_F)P[y \geq L_F] \\ & +(1-C_F)(1-C_U)(R_S)P[L_S \leq y \leq L_N] \\ & +(1-C_F)(1-C_U)(R_N)P[Y>L_N] \end{aligned}$$

Case 2

$$\begin{aligned} P_I = {} & (C_U)(R_U)P[Y \geq L_U]+(1-C_U)(R_S)P[L_S \leq Y \leq L_F] \\ & +(1-C_U)(C_F)(R_F)P[Y \geq L_F] \\ & +(1-C_U)(1-C_F)(R_S)P[L_F \leq Y \leq L_N] \\ & +(1-C_U)(1-C_F)(R_N)P[Y \geq L_N] \end{aligned}$$

Case 3

$$\begin{aligned} P_I = {} & (C_U)(R_U)P[Y \geq L_U]+(1-C_U)(R_S)P[L_S \leq Y \leq L_N] \\ & +(1-C_U)(R_N)P[Y>L_N] \end{aligned}$$

Case 4

$$\begin{aligned} P_I = {} & (C_F)(R_F)P[Y \geq L_F]+(1-C_F)(C_U)(R_F)P[Y \geq L_U] \\ & +(1-C_F)(1-C_U)(R_S)P[L_S \leq Y \leq L_N] \\ & +(1-C_F)(1-C_U)(R_N)P[Y>L_N] \end{aligned}$$

Case 5

$$\begin{aligned} P_I = {} & (C_F)(R_F)P[Y \geq L_F]+(1-C_F)(R_S)P[L_S \leq Y \leq L_U] \\ & +(1-C_F)(C_U)(R_U)P[Y \geq L_U] \\ & +(1-C_F)(1-C_U)(R_S)P[L_U \leq Y \leq L_N] \\ & +(1-C_F)(1-C_U)(R_N)P[Y>L_N] \end{aligned}$$

Case 6

$$\begin{aligned} P_I = {} & (C_F)(R_F)P[Y \geq L_F]+(1-C_F)(R_S)P[L_S \leq Y \leq L_N] \\ & +(1-C_F)(R_N)P[Y>L_N] \end{aligned}$$

Case 7

$$\begin{aligned} P_I = {} & (R_S)P[L_S \leq Y \leq L_U]+(C_U)(R_U)P[Y \geq L_U] \\ & +(1-C_U)(R_S)P[L_U \leq Y \leq L_F] \\ & +(1-C_U)(C_F)(R_F)P[Y \geq L_F] \\ & +(1-C_U)(1-C_F)(R_S)P[L_F \leq Y \leq L_N] \\ & +(1-C_U)(1-C_F)(R_N)P[Y>L_N] \end{aligned}$$

Case 8

$$\begin{aligned} P_I = {} & (R_S)P[L_S \leq Y \leq L_F]+(C_F)(R_F)P[Y \geq L_F] \\ & +(1-C_F)(R_S)P[L_F \leq Y \leq L_U] \\ & +(1-C_F)(C_U)(R_U)P[Y \geq L_U] \\ & +(1-C_F)(1-C_U)(R_S)P[L_U \leq Y \leq L_N] \\ & +(1-C_F)(1-C_U)(R_N)P[Y>L_N] \end{aligned}$$

Case 9

$$\begin{aligned} P_I = {} & (R_S)P[L \le Y \le L_U] + (C_U)(R_U)P[Y \ge L_U] \\ & + (1 - C_U)(R_S)P[L_U \le Y \le L_N] \\ & + (1 - C_U)(R_N)P[Y > L_N] \end{aligned}$$

Case 10

$$\begin{aligned} P_I = {} & (R_S)P[L_S \le Y \le L_F] + (C_F)(R_F)P[Y \ge L_F] \\ & + (1 - C_F)(R_S)P[L_F \le Y \le L_N] \\ & + (1 - C_F)(R_N)P[Y > L_N] \end{aligned}$$

Case 11

$$P_I = (R_S)P[L_S \le Y \le L_N] + (R_N)P[Y > L_N]$$

Case 12

$$\begin{aligned} P_I = {} & (R_K)P[Y \le L_U] + (C_U)(R_U)P[Y \ge L_U] \\ & + (1 - C_U)(R_K)P[L_U \le Y \le L_F] \\ & + (1 - C_U)(C_F)(R_F)P[Y \ge L_F] \\ & + (1 - C_U)(1 - C_F)(R_K)P[L_F \le Y \le L_N] \\ & + (1 - C_U)(1 - C_F)(R_N)P[Y > L_N] \end{aligned}$$

Case 13

$$\begin{aligned} P_I = {} & (R_K)P[Y \le L_F] + (C_F)(R_F)P[Y \ge L_F] \\ & + (1 - C_F)(R_K)P[L_F \le Y \le L_U] \\ & + (1 - C_F)(C_U)(R_U)P[Y \ge L_U] \\ & + (1 - C_F)(1 - C_U)(R_K)P[L_U \le Y \le L_N] \\ & + (1 - C_F)(1 - C_U)(R_N)P[Y > L_N] \end{aligned}$$

Case 14

$$\begin{aligned} P_I = {} & (R_K)P[Y \le L_U] + (C_U)(R_U)P[Y \ge L_U] \\ & + (1 - C_U)(R_K)P[L_U \le Y \le L_N] \\ & + (1 - C_U)(R_N)P[Y > L_N] \end{aligned}$$

Case 15

$$
\begin{aligned}
P_I = {} & (R_K)P[Y<L_F]+(C_F)(R_F)P[Y\geq L_F] \\
& +(1-C_F)(R_K)P[L_F<Y<L_N] \\
& +(1-C_F)(R_N)P[Y>L_N]
\end{aligned}
$$

Case 16

$$P_I = (R_K)P[Y\leq L_N]+(R_N)P[Y>L_N]$$

Coverage Factor Relationships

Assuming that a single fixed-object such as a pole has a 0.5-foot (0.2-m) square dimension, the NCHRP model yields the roadway shadow length for each object as follows:

$$\text{Shadow length} = 1/2 + 6 \csc \theta + 1/2 \cot \theta$$

Where θ = average encroachment angle, 11° for rural, and 7° for urban

Using the average angles yields the following shadow lengths:

Rural shadow length = 34.5 ft. (10.5 m)
Urban shadow length = 53.7 ft. (16.4 m)

Therefore, the coverage factors for various densities of utility poles are:

Number of utility poles per mile (1.6 km)		Coverage Factor (C_U)	
One Side	Both Sides	Urban	Rural
10	20	0.103	0.065
20	40	0.206	0.130
30	60	0.309	0.195
40	80	0.412	0.260

Exercising the Models

In exercising the models, several assumptions, simplifications, classifications, and parameter values were applied as shown in Table 24. The exceedance probabilities for the lateral displacements of encroaching

Table 26. Examples of values used in exercising the roadside hazard adjustment model.

Coverage Factor Classes for Utility Poles (C_U) and Fixed Objects (C_F)

C_U 0.065, 0.130, 0.195, 0.260

C_F 0.10, 0.35, 0.65, 0.90

Lateral Placement of Roadside Hinge Point L_X (in Feet)

$L_X = 10$

Lateral Placements of Utility Poles (L_U) and Fixed Objects (L_F) in Feet

Rural $L_U = 5, 10, 15, 20$
$L_F = 5, 10, 15, 20$

Urban $L_U = 2, 5, 10, 15$
$L_F = 2, 5, 10, 15$

Lateral Placement of Non-Clear Zone (L_N) in Feet

Rural $L_N = 30$
Urban $L_N = 20$

Exceedance Probabilities for Lateral Displacement of Encroaching Vehicles

Rural		Urban	
Lateral Displacement (Feet)	Probability	Lateral Displacement (Feet)	Probability
5	0.96	2	0.92
10	0.87	5	0.77
15	0.70	10	0.57
20	0.58	15	0.40
30	0.30	20	0.27

Reporting Level Factors

Fixed Objects $R_F = 0.90$
Utility Poles $R_U = 0.90$
Curbs $R_K = 0.10$
Nonclear Zone $R_N = 0.50$
Slopes

Fill Slope	Cut Slope	Rs
10:1	6:1	0.05
6:1	4:1	0.20
4:1	3:1	0.30
3:1	2:1	0.60

Note: 1 foot = 0.3 m

vehicles were taken from "Effectiveness of Roadside Safety Improvements" by Glennon and Wilton [2] as illustrated in Figures 30 and 31 for urban and rural areas, respectively. The reporting level factors were subjectively estimated from the NCHRP Report 247 results [3].

Computing the Roadside Adjustment Factor

To compute the roadside adjustment factor, the following steps should be made:

Step 1: For the existing roadside condition, list the values of L_U (the average lateral offsets of the utility poles), L_F (average offset of fixed objects), L_S (distance of break in slope if in a rural area), and L_N (lateral distance at which the nonclear zone begins).

Step 2: Repeat Step 1 for the condition expected after the countermeasure is implemented. For example, if poles are to be relocated from 4 foot lateral offsets to 20 feet (1.2 to 6.1 m), then L_U would be 20 after the improvement, and values of L_F, L_N, and L_F might remain constant.

Step 3: Determine which of the 16 cases apply during the existing condition and also during the after condition, based on the order of obstacles from the roadway edge.

Step 4: Determine values of R_U, R_F, R_N, L_S, $P[Y>L_N]$, and R_K for the before conditions and after condition. Note that values of $P[Y>L_N]$ differ for urban and rural areas.

Step 5: Compute P_U = the probability of a utility pole accident, independent of other roadside conditions, as follows:

$$P_U = (C_U)(R_U)P[Y \geq L_U]$$

for both the before condition and the after condition.

Step 6: Compute ΔP_U the change in P_U value expected after the countermeasure.

$$\Delta P_U = P_{U1} - P_{U2}$$

where: P_{U1} = Probability of a utility pole accident in the before condition.

P_{U2} = Probability of a utility pole accident after the countermeasure is completed.

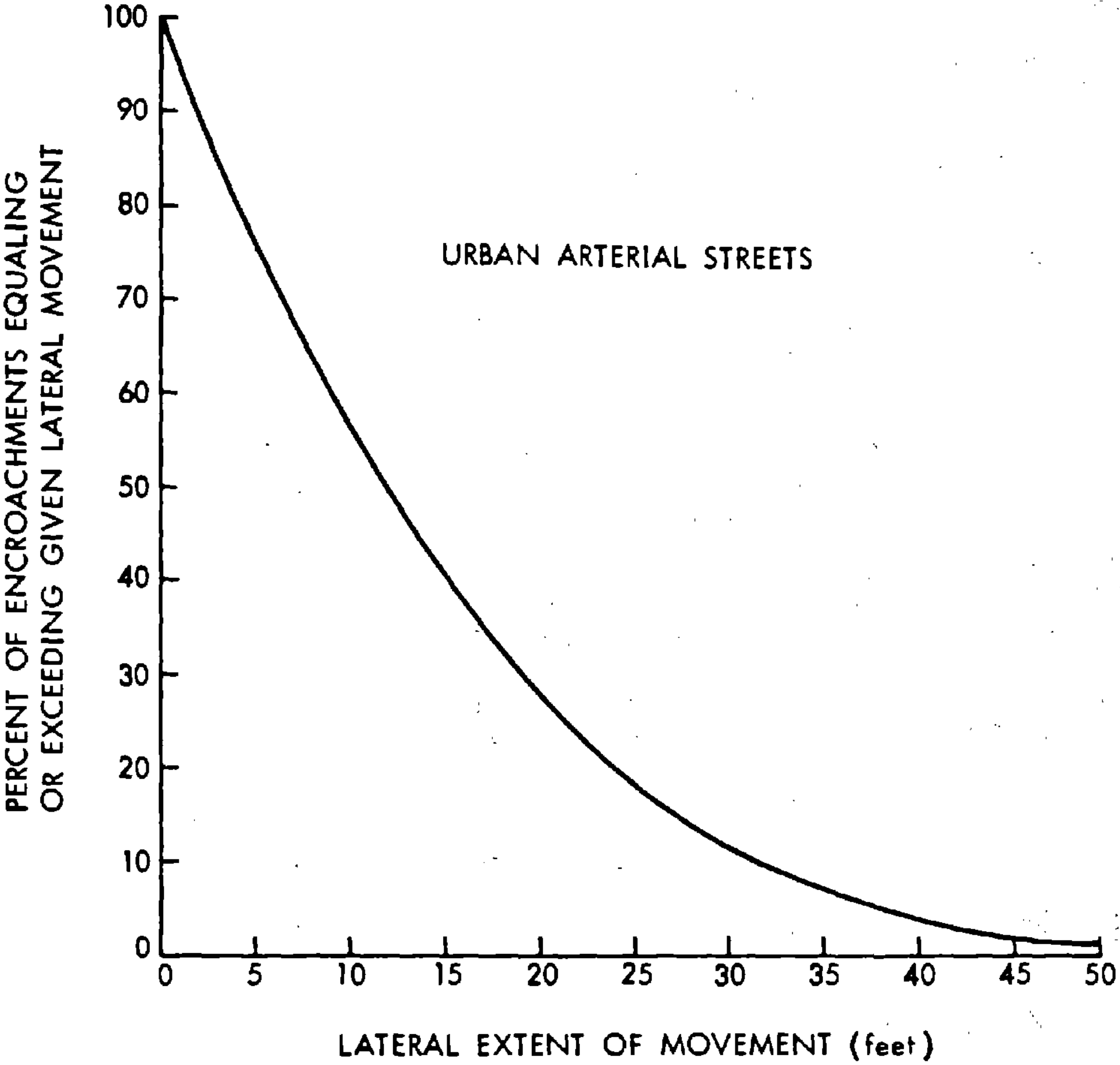

Figure 30. Estimated exceedance distribution of lateral displacement of encroaching vehicles for urban arterial streets.

Source: Reference 2

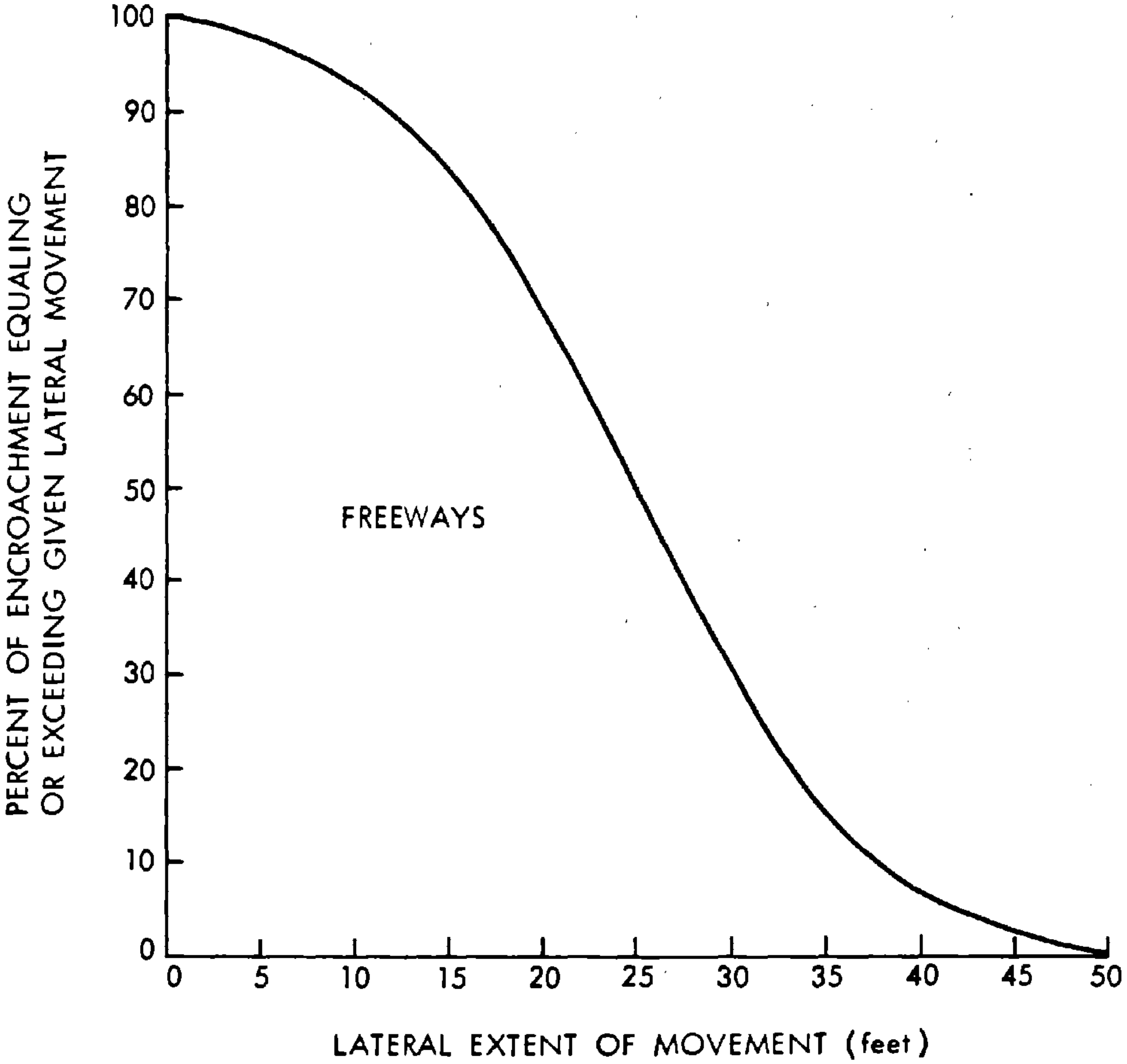

Figure 31. Exceedance distribution of lateral displacement of encroaching vehicles for freeway medians.

Source: Reference 2

Step 7: Compute ΔP_I (the probability of any roadside accident for both the before and after conditions.

Step 8: Compute: $\Delta P_I = P_{I1} - P_{I2}$

where, P_{I1} = Probability of roadside accident in the before condition.

P_{I2} = Probability of a roadside accident in the after condition.

Step 9: Compute the roadside adjustment factor = H_R

where, $H_R = \Delta P_I / \Delta P_U$

Step 10: To determine the net reduction in total roadside object accidents due to a utility pole countermeasure, multiply H_R by the expected reduction in utility pole accidents.

References

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APPENDIX B - ACCIDENT REDUCTION FACTORS FOR UTILITY POLE ACCIDENTS

Increasing Lateral Pole Offsets

Accident reduction factors were developed based on the predictive model and correspond to the expected reduction in utility pole accidents due to increasing lateral pole offsets. The accident reduction factors (AR factors) given in the table 25 were developed for a variety of traffic volumes and pole densities. The AR factors are expressed as the percent reductions in utility pole accidents expected due to moving poles from one pole offset back to another distance further from the roadway. For example, the first table corresponds to roadways with a traffic volume of 1,000 and pole densities of 20 poles per mile (12 poles/km). Assuming an existing line of poles with 5 foot (1.5 m) offsets will be moved back to 20 feet (6.1 m), the expected reduction in utility pole accidents is 65 percent, as shown in the table.

These AR factors only apply to utility pole accidents and to not account for the possible increase in other roadside accidents which may occur after the poles are relocated. For example, if utility poles are moved from 5 feet (1.5 m) to 20 feet (6.1 m) from the roadway, an encroaching vehicle might then hit a tree or other obstacle instead of a utility pole. Roadside adjustment factors to account for this situation are given in the text and further discussed in Appendix A.

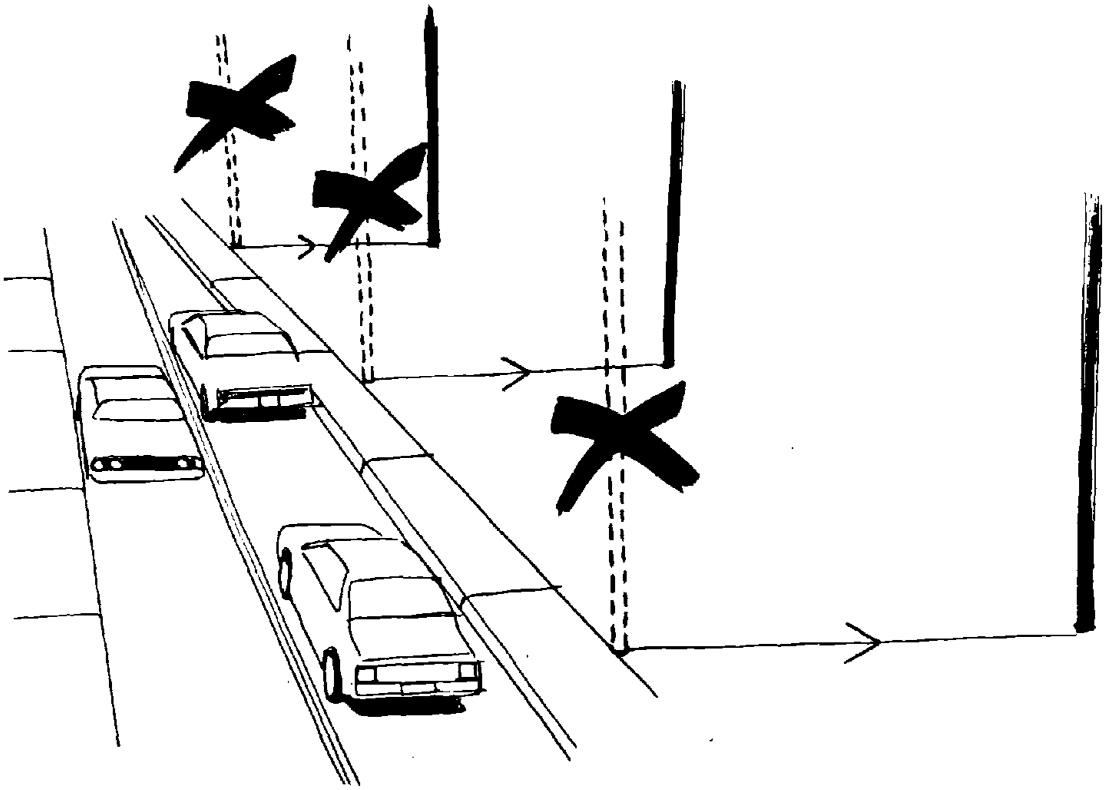

Table 27. Accident reduction factors due to increasing lateral pole offsets for various levels of traffic volume and pole density.

ADT LEVEL 1000. POLE DENSITY 20. POLES/MILE

POLE OFFSET BEFORE IMPROVEMENT (FEET)	POLE OFFSET AFTER IMPROVEMENT (FEET)								
	6.	8.	10.	12.	15.	17.	20.	25.	30.
2.	52.	61.	67.	72.	76.	78.	81.	85.	87.
3.	38.	49.	57.	63.	69.	72.	76.	80.	83.
4.	25.	39.	48.	55.	62.	66.	70.	76.	80.
5.	12.	28.	39.	47.	56.	60.	65.	72.	76.
6.	-	19.	31.	40.	50.	55.	61.	68.	73.
7.	-	9.	23.	33.	44.	50.	56.	64.	70.
8.	-	-	15.	26.	38.	44.	52.	60.	67.
9.	-	-	8.	20.	33.	39.	47.	57.	64.
10.	-	-	-	13.	27.	34.	43.	53.	61.
11.	-	-	-	7.	22.	29.	39.	50.	58.
12.	-	-	-	-	16.	25.	34.	46.	55.
13.	-	-	-	-	11.	20.	30.	43.	52.
14.	-	-	-	-	5.	15.	26.	39.	49.
15.	-	-	-	-	-	10.	22.	36.	46.

ADT LEVEL 1000. POLE DENSITY 40. POLES/MILE

POLE OFFSET BEFORE IMPROVEMENT (FEET)	POLE OFFSET AFTER IMPROVEMENT (FEET)								
	6.	8.	10.	12.	15.	17.	20.	25.	30.
2.	50.	59.	65.	69.	73.	75.	78.	81.	84.
3.	36.	47.	54.	60.	65.	68.	72.	76.	79.
4.	23.	36.	45.	52.	58.	62.	66.	71.	75.
5.	11.	26.	37.	44.	52.	56.	61.	67.	71.
6.	-	17.	29.	37.	46.	51.	56.	63.	67.
7.	-	8.	21.	30.	40.	45.	51.	59.	64.
8.	-	-	14.	24.	35.	40.	47.	55.	61.
9.	-	-	7.	18.	29.	35.	42.	51.	57.
10.	-	-	-	12.	24.	31.	38.	48.	54.
11.	-	-	-	6.	19.	26.	34.	44.	51.
12.	-	-	-	-	14.	22.	30.	41.	48.
13.	-	-	-	-	9.	17.	26.	37.	45.
14.	-	-	-	-	5.	13.	22.	34.	42.
15.	-	-	-	-	-	8.	18.	31.	40.

ADT LEVEL 1000. POLE DENSITY 75. POLES/MILE

POLE OFFSET BEFORE IMPROVEMENT (FEET)	POLE OFFSET AFTER IMPROVEMENT (FEET)								
	6.	8.	10.	12.	15.	17.	20.	25.	30.
2.	49.	58.	63.	67.	72.	74.	77.	80.	82.
3.	35.	46.	53.	58.	64.	67.	70.	74.	77.
4.	22.	35.	44.	50.	57.	60.	64.	69.	73.
5.	11.	26.	35.	43.	50.	54.	59.	65.	69.
6.	-	17.	28.	36.	44.	49.	54.	60.	65
7.	-	8.	20.	29.	39.	43.	49.	56.	61.
8.	-	-	13.	23.	33.	38.	45.	52.	58.
9.	-	-	6.	17.	28.	34.	40.	49.	55.
10.	-	-	-	11.	23.	29.	36.	45.	51.
11.	-	-	-	5.	18.	25.	32.	42.	48.
12.	-	-	-	-	13.	20.	28.	38.	45.
13.	-	-	-	-	9.	16.	25.	35.	42.
14.	-	-	-	-	4.	12.	21.	32.	40.
15.	-	-	-	-	-	8.	17.	29.	37.

Table 27. Accident reduction factors due to increasing lateral pole offsets for various levels of traffic volume and pole density (Continued).

ADT LEVEL 5000. POLE DENSITY 20. POLES/MILE

POLE OFFSET BEFORE IMPROVEMENT (FEET)	POLE OFFSET AFTER IMPROVEMENT (FEET)								
	6.	8.	10.	12.	15.	17.	20.	25.	30.
2.	51.	60.	65.	70.	74.	76.	79.	82.	85.
3.	36.	48.	55.	61.	66.	69.	73.	77.	80.
4.	23.	37.	46.	52.	60.	63.	67.	73.	76.
5.	11.	27.	37.	45.	53.	57.	62.	68.	73.
6.	-	18.	29.	38.	47.	52.	57.	64.	69.
7.	-	9.	22.	31.	41.	47.	53.	60.	66.
8.	-	-	14.	25.	36.	41.	48.	56.	62.
9.	-	-	7.	18.	30.	36.	44.	53.	59.
10.	-	-	-	12.	25.	32.	40.	49.	56.
11.	-	-	-	6.	20.	27.	35.	46.	53.
12.	-	-	-	-	15.	22.	31.	42.	50.
13.	-	-	-	-	10.	18.	27.	39.	47.
14.	-	-	-	-	5.	13.	23.	35.	44.
15.	-	-	-	-	-	9.	19.	32.	41.

ADT LEVEL 5000. POLE DENSITY 40. POLES/MILE

POLE OFFSET BEFORE IMPROVEMENT (FEET)	POLE OFFSET AFTER IMPROVEMENT (FEET)								
	6.	8.	10.	12.	15.	17.	20.	25.	30.
2.	50.	58.	64.	68.	73.	75.	77.	81.	83.
3.	36.	46.	54.	59.	65.	68.	71.	75.	78.
4.	23.	36.	45.	51.	58.	61.	65.	70.	74.
5.	11.	26.	36.	43.	51.	55.	60.	66.	70.
6.	-	17.	28.	36.	45.	50.	55.	61.	66.
7.	-	8.	21.	30.	39.	44.	50.	57.	63.
8.	-	-	14.	23.	34.	39.	46.	54.	59.
9.	-	-	7.	17.	29.	35.	41.	50.	56.
10.	-	-	-	11.	24.	30.	37.	46.	53.
11.	-	-	-	6.	19.	25.	33.	43.	50.
12.	-	-	-	-	14.	21.	29.	39.	47.
13.	-	-	-	-	9.	17.	25.	36.	44.
14.	-	-	-	-	5.	12.	22.	33.	41.
15.	-	-	-	-	-	8.	18.	30.	38.

ADT LEVEL 5000. POLE DENSITY 75. POLES/MILE

POLE OFFSET BEFORE IMPROVEMENT (FEET)	POLE OFFSET AFTER IMPROVEMENT (FEET)								
	6.	8.	10.	12.	15.	17.	20.	25.	30.
2.	49.	58.	63.	67.	72.	74.	76.	80.	82.
3.	35.	46.	53.	58.	64.	66.	70.	74.	77.
4.	22.	35.	44.	50.	56.	60.	64.	69.	72.
5.	11.	25.	35.	42.	50.	54.	59.	64.	68.
6.	-	16.	27.	35.	44.	48.	54.	60.	64.
7.	-	8.	20.	29.	38.	43.	49.	56.	61.
8.	-	-	13.	23.	33.	38.	44.	52.	57.
9.	-	-	6.	17.	28.	33.	40.	48.	54.
10.	-	-	-	11.	23.	29.	36.	45.	51.
11.	-	-	-	5.	18.	24.	32.	41.	48.
12.	-	-	-	-	13.	20.	28.	38.	45.
13.	-	-	-	-	9.	16.	24.	35.	42.
14.	-	-	-	-	4.	12.	21.	31.	39.
15.	-	-	-	-	-	8.	17.	28.	36.

Table 27. Accident reduction factors due to increasing lateral pole offsets for various levels of traffic volume and pole density (Continued).

ADT LEVEL 10000. POLE DENSITY 20. POLES/MILE

POLE OFFSET BEFORE IMPROVEMENT (FEET)	POLE OFFSET AFTER IMPROVEMENT (FEET)								
	6.	8.	10.	12.	15.	17.	20.	25.	30.
2.	50.	59.	64.	68.	73.	75.	78.	81.	83.
3.	36.	47.	54.	59.	65.	68.	71.	76.	79.
4.	23.	36.	45.	51.	58.	62.	66.	71.	74.
5.	11.	26.	36.	44.	52.	56.	60.	66.	70.
6.	-	17.	28.	37.	46.	50.	55.	62.	67.
7.	-	8.	21.	30.	40.	45.	51.	58.	63.
8.	-	-	14.	24.	34.	40.	46.	54.	60.
9.	-	-	7.	17.	29.	35.	42.	51.	57.
10.	-	-	-	11.	24.	30.	38.	47.	54.
11.	-	-	-	6.	19.	26.	34.	43.	51.
12.	-	-	-	-	14.	21.	30.	40.	48.
13.	-	-	-	-	9.	17.	26.	37.	45.
14.	-	-	-	-	5.	13.	22.	33.	42.
15.	-	-	-	-	-	8.	18.	30.	39.

ADT LEVEL 10000. POLE DENSITY 40. POLES/MILE

POLE OFFSET BEFORE IMPROVEMENT (FEET)	POLE OFFSET AFTER IMPROVEMENT (FEET)								
	6.	8.	10.	12.	15.	17.	20.	25.	30.
2.	50.	58.	64.	68.	72.	74.	77.	80.	82.
3.	35.	46.	53.	58.	64.	67.	70.	74.	77.
4.	22.	35.	44.	50.	57.	60.	65.	69.	73.
5.	11.	26.	36.	43.	51.	55.	59.	65.	69.
6.	-	17.	28.	36.	45.	49.	54.	61.	65.
7.	-	8.	20.	29.	39.	44.	50.	57.	62.
8.	-	-	13.	23.	33.	39.	45.	53.	58.
9.	-	-	7.	17.	28.	34.	41.	49.	55.
10.	-	-	-	11.	23.	29.	37.	45.	52.
11.	-	-	-	5.	18.	25.	33.	42.	49.
12.	-	-	-	-	14.	20.	29.	39.	46.
13.	-	-	-	-	9.	16.	25.	35.	43.
14.	-	-	-	-	4.	12.	21.	32.	40.
15.	-	-	-	-	-	8.	17.	29.	37.

ADT LEVEL 10000. POLE DENSITY 75. POLES/MILE

POLE OFFSET BEFORE IMPROVEMENT (FEET)	POLE OFFSET AFTER IMPROVEMENT (FEET)								
	6.	8.	10.	12.	15.	17.	20.	25.	30.
2.	49.	57.	63.	67.	71.	74.	76.	79.	82.
3.	35.	45.	53.	58.	63.	66.	70.	74.	77.
4.	22.	35.	43.	50.	56.	60.	64.	69.	72.
5.	11.	25.	35.	42.	50.	54.	58.	64.	68.
6.	-	16.	27.	35.	44.	48.	53.	60.	64.
7.	-	8.	20.	29.	38.	43.	49.	55.	60.
8.	-	-	13.	22.	33.	38.	44.	52.	57.
9.	-	-	6.	17.	28.	33.	40.	48.	54.
10.	-	-	-	11.	23.	29.	36.	44.	51.
11.	-	-	-	5.	18.	24.	32.	41.	48.
12.	-	-	-	-	13.	20.	28.	38.	45.
13.	-	-	-	-	9.	16.	24.	34.	42.
14.	-	-	-	-	4.	12.	20.	31.	39.
15.	-	-	-	-	-	8.	17.	28.	36.

Table 27. Accident reduction factors due to increasing lateral pole offsets for various levels of traffic volume and pole density (Continued).

ADT LEVEL 15000. POLE DENSITY 20. POLES/MILE

POLE OFFSET BEFORE IMPROVEMENT (FEET)	POLE OFFSET AFTER IMPROVEMENT (FEET) 6.	8.	10.	12.	15.	17.	20.	25.	30.
2.	50.	58.	64.	68.	72.	74.	77.	80.	83.
3.	35.	46.	53.	59.	64.	67.	71.	75.	78.
4.	23.	36.	44.	50.	57.	61.	65.	70.	73.
5.	11.	26.	36.	43.	51.	55.	59.	65.	69.
6.	-	17.	28.	36.	45.	49.	55.	61.	66.
7.	-	8.	21.	29.	39.	44.	50.	57.	62.
8.	-	-	13.	23.	34.	39.	45.	53.	59.
9.	-	-	7.	17.	28.	34.	41.	49.	55.
10.	-	-	-	11.	23.	30.	37.	46.	52.
11.	-	-	-	6.	18.	25.	33.	42.	49.
12.	-	-	-	-	14.	21.	29.	39.	46.
13.	-	-	-	-	9.	16.	25.	36.	43.
14.	-	-	-	-	4.	12.	21.	32.	40.
15.	-	-	-	-	-	8.	18.	29.	38.

ADT LEVEL 15000. POLE DENSITY 40. POLES/MILE

POLE OFFSET BEFORE IMPROVEMENT (FEET)	POLE OFFSET AFTER IMPROVEMENT (FEET) 6.	8.	10.	12.	15.	17.	20.	25.	30.
2.	49.	58.	63.	67.	72.	74.	77.	80.	82.
3.	35.	46.	53.	58.	64.	67.	70.	74.	77.
4.	22.	35.	44.	50.	57.	60.	64.	69.	73.
5.	11.	26.	35.	42.	50.	54.	59.	64.	68.
6.	-	17.	28.	36.	44.	49.	54.	60.	65.
7.	-	8.	20.	29.	38.	43.	49.	56.	61.
8.	-	-	13.	23.	33.	38.	45.	52.	58.
9.	-	-	6.	17.	28.	34.	40.	48.	54.
10.	-	-	-	11.	23.	29.	36.	45.	51.
11.	-	-	-	5.	18.	24.	32.	41.	48.
12.	-	-	-	-	13.	20.	28.	38.	45.
13.	-	-	-	-	9.	16.	24.	35.	42.
14.	-	-	-	-	4.	12.	21.	32.	39.
15.	-	-	-	-	-	8.	17.	28.	37.

ADT LEVEL 15000. POLE DENSITY 75. POLES/MILE

POLE OFFSET BEFORE IMPROVEMENT (FEET)	POLE OFFSET AFTER IMPROVEMENT (FEET) 6.	8.	10.	12.	15.	17.	20.	25.	30.
2.	49.	57.	63.	67.	71.	73.	76.	79.	82.
3.	35.	45.	52.	58.	63.	66.	69.	73.	76.
4.	22.	35.	43.	49.	56.	59.	63.	68.	72.
5.	11.	25.	35.	42.	50.	53.	58.	64.	68.
6.	-	16.	27.	35.	44.	48.	53.	59.	64.
7.	-	8.	20.	29.	38.	43.	48.	55.	60.
8.	-	-	13.	22.	33.	38.	44.	51.	57.
9.	-	-	6.	16.	27.	33.	40.	48.	53.
10.	-	-	-	11.	23.	28.	35.	44.	50.
11.	-	-	-	5.	18.	24.	31.	41.	47.
12.	-	-	-	-	13.	20.	28.	37.	44.
13.	-	-	-	-	9.	16.	24.	34.	41.
14.	-	-	-	-	4.	12.	20.	31.	39.
15.	-	-	-	-	-	8.	17.	28.	36.

Table 27. Accident reduction factors due to increasing lateral pole offsets for various levels of traffic volume and pole density (Continued).

ADT LEVEL 25000. POLE DENSITY 20. POLES/MILE

POLE OFFSET BEFORE IMPROVEMENT (FEET)	POLE OFFSET AFTER IMPROVEMENT (FEET) 6.	8.	10.	12.	15.	17.	20.	25.	30.
2.	49.	58.	63.	67.	72.	74.	76.	80.	82.
3.	35.	46.	53.	58.	64.	66.	70.	74.	77.
4.	22.	35.	44.	50.	56.	60.	64.	69.	72.
5.	11.	25.	35.	42.	50.	54.	59.	64.	68.
6.	-	16.	27.	35.	44.	48.	54.	60.	64.
7.	-	8.	20.	29.	38.	43.	49.	56.	61.
8.	-	-	13.	23.	33.	38.	44.	52.	57.
9.	-	-	6.	17.	28.	33.	40.	48.	54.
10.	-	-	-	11.	23.	29.	36.	45.	51.
11.	-	-	-	5.	18.	24.	32.	41.	48.
12.	-	-	-	-	13.	20.	28.	38.	45.
13.	-	-	-	-	9.	16.	24.	35.	42.
14.	-	-	-	-	4.	12.	21.	31.	39.
15.	-	-	-	-	-	8.	17.	28.	36.

ADT LEVEL 25000. POLE DENSITY 40. POLES/MILE

POLE OFFSET BEFORE IMPROVEMENT (FEET)	POLE OFFSET AFTER IMPROVEMENT (FEET) 6.	8.	10.	12.	15.	17.	20.	25.	30.
2.	49.	57.	63.	67.	71.	74.	76.	79.	82.
3.	35.	45.	53.	58.	63.	66.	69.	74.	76.
4.	22.	35.	43.	50.	56.	60.	64.	68.	72.
5.	11.	25.	35.	42.	50.	54.	58.	64.	68.
6.	-	16.	27.	35.	44.	48.	53.	59.	64.
7.	-	8.	20.	29.	38.	43.	48.	55.	60.
8.	-	-	13.	22.	33.	38.	44.	51.	57.
9.	-	-	6.	17.	28.	33.	40.	48.	54.
10.	-	-	-	11.	23.	28.	36.	44.	50.
11.	-	-	-	5.	18.	24.	32.	41.	47.
12.	-	-	-	-	13.	20.	28.	37.	44.
13.	-	-	-	-	9.	16.	24.	34.	42.
14.	-	-	-	-	4.	12.	20.	31.	39.
15.	-	-	-	-	-	8.	17.	28.	36.

ADT LEVEL 25000. POLE DENSITY 75. POLES/MILE

POLE OFFSET BEFORE IMPROVEMENT (FEET)	POLE OFFSET AFTER IMPROVEMENT (FEET) 6.	8.	10.	12.	15.	17.	20.	25.	30.
2.	49.	57.	63.	67.	71.	73.	76.	79.	81.
3.	35.	45.	52.	57.	63.	66.	69.	73.	76.
4.	22.	35.	43.	49.	56.	59.	63.	68.	71.
5.	11.	25.	35.	42.	49.	53.	58.	63.	67.
6.	-	16.	27.	35.	43.	48.	53.	59.	63.
7.	-	8.	20.	28.	38.	42.	48.	55.	60.
8.	-	-	13.	22.	32.	37.	44.	51.	56.
9.	-	-	6.	16.	27.	33.	39.	47.	53.
10.	-	-	-	11.	22.	28.	35.	44.	50.
11.	-	-	-	5.	18.	24.	31.	40.	47.
12.	-	-	-	-	13.	20.	27.	37.	44.
13.	-	-	-	-	9.	15.	24.	34.	41.
14.	-	-	-	-	4.	11.	20.	31.	38.
15.	-	-	-	-	-	8.	17.	28.	36.

Table 27. Accident reduction factors due to increasing lateral pole offsets for various levels of traffic volume and pole density (Continued).

ADT LEVEL 40000. POLE DENSITY 40. POLES/MILE

POLE OFFSET BEFORE IMPROVEMENT (FEET)	POLE OFFSET AFTER IMPROVEMENT (FEET) 6.	8.	10.	12.	15.	17.	20.	25.	30.
2.	49.	57.	63.	67.	71.	73.	76.	79.	81.
3.	35.	45.	52.	57.	63.	66.	69.	73.	76.
4.	22.	35.	43.	49.	56.	59.	63.	68.	71.
5.	11.	25.	35.	42.	49.	53.	58.	63.	67.
6.	-	16.	27.	35.	43.	48.	53.	59.	63.
7.	-	8.	20.	28.	38.	42.	48.	55.	60.
8.	-	-	13.	22.	32.	37.	43.	51.	56.
9.	-	-	6.	16.	27.	33.	39.	47.	53.
10.	-	-	-	11.	22.	28.	35.	44.	50.
11.	-	-	-	5.	18.	24.	31.	40.	47.
12.	-	-	-	-	13.	20.	27.	37.	44.
13.	-	-	-	-	9.	15.	24.	34.	41.
14.	-	-	-	-	4.	11.	20.	31.	38.
15.	-	-	-	-	-	8.	17.	27.	35.

ADT LEVEL 40000. POLE DENSITY 75. POLES/MILE

POLE OFFSET BEFORE IMPROVEMENT (FEET)	POLE OFFSET AFTER IMPROVEMENT (FEET) 6.	8.	10.	12.	15.	17.	20.	25.	30.
2.	49.	57.	63.	67.	71.	73.	76.	79.	81.
3.	34.	45.	52.	57.	63.	65.	69.	73.	76.
4.	22.	35.	43.	49.	56.	59.	63.	68.	71.
5.	11.	25.	35.	42.	49.	53.	57.	63.	67.
6.	-	16.	27.	35.	43.	47.	52.	59.	63.
7.	-	8.	20.	28.	37.	42.	48.	55.	59.
8.	-	-	13.	22.	32.	37.	43.	51.	56.
9.	-	-	6.	16.	27.	32.	39.	47.	53.
10.	-	-	-	11.	22.	28.	35.	43.	50.
11.	-	-	-	5.	17.	24.	31.	40.	46.
12.	-	-	-	-	13.	19.	27.	37.	44.
13.	-	-	-	-	8.	15.	23.	33.	41.
14.	-	-	-	-	4.	11.	20.	30.	38.
15.	-	-	-	-	-	7.	16.	27.	35.

ADT LEVEL 40000. POLE DENSITY 20. POLES/MILE

POLE OFFSET BEFORE IMPROVEMENT (FEET)	POLE OFFSET AFTER IMPROVEMENT (FEET) 6.	8.	10.	12.	15.	17.	20.	25.	30.
2.	49.	57.	63.	67.	71.	73.	76.	79.	81.
3.	35.	45.	52.	57.	63.	66.	69.	73.	76.
4.	22.	35.	43.	49.	56.	59.	63.	68.	72.
5.	11.	25.	35.	42.	49.	53.	58.	63.	67.
6.	-	16.	27.	35.	43.	48.	53.	59.	64.
7.	-	8.	20.	28.	38.	43.	48.	55.	60.
8.	-	-	13.	22.	32.	38.	44.	51.	57.
9.	-	-	6.	16.	27.	33.	39.	47.	53.
10.	-	-	-	11.	22.	28.	35.	44.	50.
11.	-	-	-	5.	18.	24.	31.	40.	47.
12.	-	-	-	-	13.	20.	28.	37.	44.
13.	-	-	-	-	9.	16.	24.	34.	41.
14.	-	-	-	-	4.	12.	20.	31.	38.
15.	-	-	-	-	-	8.	17.	28.	36.

Table 27. Accident reduction factors due to increasing lateral pole offsets for various levels of traffic volume and pole density (Continued).

ADT LEVEL 60000. POLE DENSITY 20. POLES/MILE

POLE OFFSET BEFORE IMPROVEMENT (FEET)	POLE OFFSET AFTER IMPROVEMENT (FEET)								
	6.	8.	10.	12.	15.	17.	20.	25.	30.
2.	49.	57.	63.	67.	71.	73.	76.	79.	81.
3.	34.	45.	52.	57.	63.	65.	69.	73.	76.
4.	22.	35.	43.	49.	56.	59.	63.	68.	71.
5.	11.	25.	35.	42.	49.	53.	57.	63.	67.
6.	-	16.	27.	35.	43.	47.	52.	59.	63.
7.	-	8.	20.	28.	37.	42.	48.	55.	59.
8.	-	-	13.	22.	32.	37.	43.	51.	56.
9.	-	-	6.	16.	27.	32.	39.	47.	53.
10.	-	-	-	11.	22.	28.	35.	43.	50.
11.	-	-	-	5.	17.	24.	31.	40.	46.
12.	-	-	-	-	13.	19.	27.	37.	44.
13.	-	-	-	-	8.	15.	23.	33.	41.
14.	-	-	-	-	4.	11.	20.	30.	38.
15.	-	-	-	-	-	7.	16.	27.	35.

ADT LEVEL 60000. POLE DENSITY 40. POLES/MILE

POLE OFFSET BEFORE IMPROVEMENT (FEET)	POLE OFFSET AFTER IMPROVEMENT (FEET)								
	6.	8.	10.	12.	15.	17.	20.	25.	30.
2.	49.	57.	62.	66.	71.	73.	76.	79.	81.
3.	34.	45.	52.	57.	63.	65.	69.	73.	76.
4.	22.	34.	43.	49.	55.	59.	63.	68.	71.
5.	11.	25.	35.	41.	49.	53.	57.	63.	67.
6.	-	16.	27.	35.	43.	47.	52.	59.	63.
7.	-	8.	20.	28.	37.	42.	48.	54.	59.
8.	-	-	13.	22.	32.	37.	43.	51.	56.
9.	-	-	6.	16.	27.	32.	39.	47.	53.
10.	-	-	-	11.	22.	28.	35.	43.	49.
11.	-	-	-	5.	17.	24.	31.	40.	46.
12.	-	-	-	-	13.	19.	27.	37.	43.
13.	-	-	-	-	8.	15.	23.	33.	41.
14.	-	-	-	-	4.	11.	20.	30.	38.
15.	-	-	-	-	-	7.	16.	27.	35.

ADT LEVEL 60000. POLE DENSITY 75. POLES/MILE

POLE OFFSET BEFORE IMPROVEMENT (FEET)	POLE OFFSET AFTER IMPROVEMENT (FEET)								
	6.	8.	10.	12.	15.	17.	20.	25.	30.
2.	49.	57.	62.	66	71.	73.	75.	79.	81.
3.	34.	45.	52.	57.	63.	65.	69.	73.	76.
4.	22.	34.	43.	49.	55.	59.	63.	67.	71.
5.	10.	25.	34.	41.	49.	53.	57.	63.	67.
6.	-	16.	27.	35.	43.	47.	52.	58.	63.
7.	-	8.	20.	28.	37.	42.	47.	54.	59.
8.	-	-	13.	22.	32.	37.	43.	50.	56.
9.	-	-	6.	16.	27.	32.	39.	47.	52.
10.	-	-	-	11.	22.	28.	35.	43.	49.
11.	-	-	-	5.	17.	23.	31.	40.	46.
12.	-	-	-	-	13.	19.	27.	36.	43.
13.	-	-	-	-	8.	15.	23.	33.	40.
14.	-	-	-	-	4.	11.	20.	30.	38.
15.	-	-	-	-	-	7.	16.	27.	35.

Reducing Pole Density

Based on the predictive model developed in the study, accident reduction factors were developed for reducing the number of poles on a given roadway section as shown in table 28. Countermeasures which may involve reducing pole density include: (1) increasing the pole spacing, (2) the use of poles for multiple purposes; and (3) the use of one line of poles instead of two lines.

The accident reduction factors (AR factors) in table 26 were derived for a variety of traffic volumes and pole offsets. Values in the tables are percent reduction in utility pole accidents expected due to a given reduction in pole density. For example, the first table corresponds to roads with a traffic volume of 1,000 and pole offsets of 3 feet (0.9 m). Assume that a mile (1.6 km) of roadway with those conditions currently has a total of 80 poles per mile (50 poles/km) on both sides of the road (40 poles on each side of the road). A proposed countermeasure is multiple pole use, where one line of poles would be removed and all utility lines would be strung on one side of the road. According to the table, reducing the number of poles from 80 to 40 would result in a 50 percent reduction in utility pole accidents.

Note that these AR factors only apply to utility pole accidents and do not account for the possible increase in other roadside accidents which may occur after some of the utility poles are taken out. For example, if a utility pole is removed, an encroaching vehicle might then hit another obstacle which had been beside or behind the utility pole. Roadway adjustment factors to account for this situation are given in the text and further discussed in Appendix A.

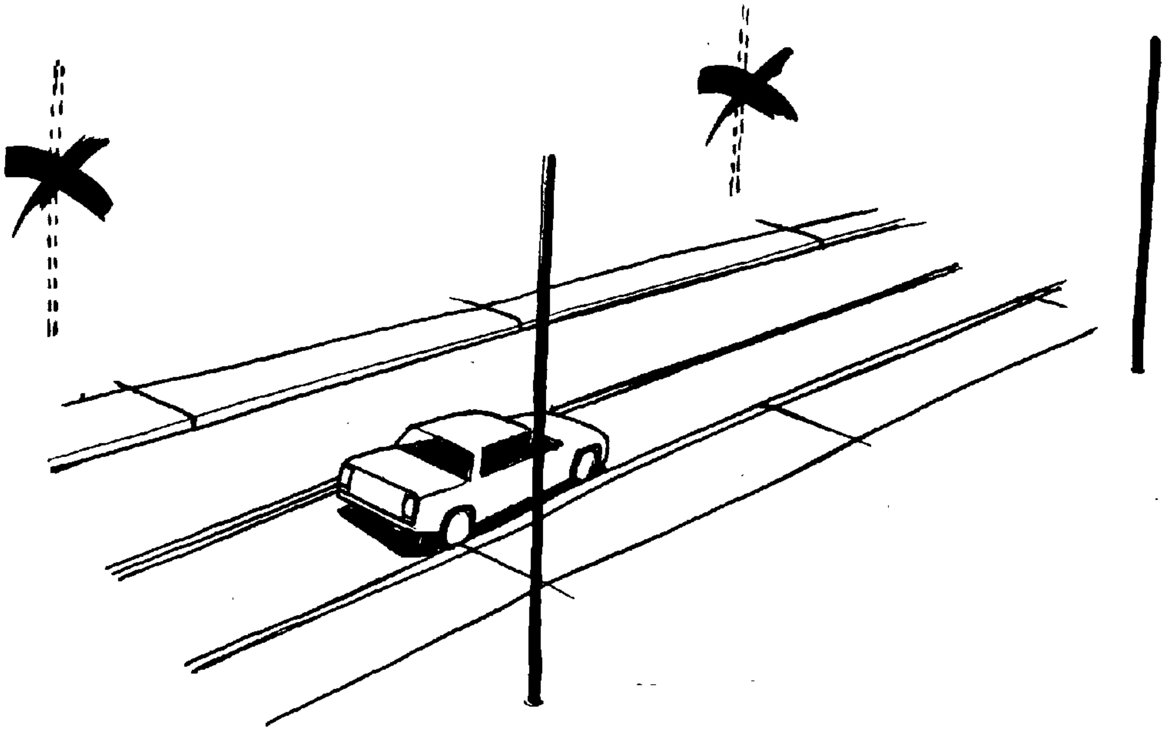

Table 28. Accident reduction factors due to increasing pole density for various levels of traffic volume and pole offsets.

ADT LEVEL 1000. POLE OFFSET 3. FEET

POLE DENSITY BEFORE IMPROVEMENT (POLES/MILE)	POLE DENSITY AFTER IMPROVEMENT (POLES/MILE)						
	10.	20.	30.	40.	50.	60.	70.
20.	49.	-	-	-	-	-	-
30.	66.	33.	-	-	-	-	-
40.	74.	49.	25.	-	-	-	-
50.	79.	59.	40.	20.	-	-	-
60.	83.	66.	50.	33.	17.	-	-
70.	85.	71.	57.	43.	28.	14.	-
80.	87.	75.	62.	50.	37.	25.	12.
90.	88.	77.	66.	55.	44.	33.	22.

ADT LEVEL 1000. POLE OFFSET 15. FEET

POLE DENSITY BEFORE IMPROVEMENT (POLES/MILE)	POLE DENSITY AFTER IMPROVEMENT (POLES/MILE)						
	10.	20.	30.	40.	50.	60.	70.
20.	60.	-	-	-	-	-	-
30.	75.	37.	-	-	-	-	-
40.	82.	54.	27.	-	-	-	-
50.	86.	64.	43.	21.	-	-	-
60.	88.	70.	53.	35.	18.	-	-
70.	90.	75.	60.	45.	30.	15.	-
80.	91.	78.	65.	52.	39.	26.	13.
90.	92.	81.	69.	58.	46.	35.	23.

ADT LEVEL 1000. POLE OFFSET 7. FEET

POLE DENSITY BEFORE IMPROVEMENT (POLES/MILE)	POLE DENSITY AFTER IMPROVEMENT (POLES/MILE)						
	10.	20.	30.	40.	50.	60.	70.
20.	53.	-	-	-	-	-	-
30.	69.	35.	-	-	-	-	-
40.	77.	51.	26.	-	-	-	-
50.	82.	61.	41.	20.	-	-	-
60.	85.	68.	51.	34.	17.	-	-
70.	87.	72.	58.	43.	29.	14.	-
80.	89.	76.	63.	51.	38.	25.	13.
90.	90.	79.	67.	56.	45.	34.	22.

ADT LEVEL 1000. POLE OFFSET 25. FEET

POLE DENSITY BEFORE IMPROVEMENT (POLES/MILE)	POLE DENSITY AFTER IMPROVEMENT (POLES/MILE)						
	10.	20.	30.	40.	50.	60.	70.
20.	68.	-	-	-	-	-	-
30.	81.	41.	-	-	-	-	-
40.	87.	58.	29.	-	-	-	-
50.	90.	67.	45.	22.	-	-	-
60.	92.	73.	55.	37.	18.	-	-
70.	93.	77.	62.	46.	31.	15.	-
80.	94.	80.	67.	54.	40.	27.	13.
90.	95.	83.	71.	59.	47.	35.	24.

Table 28. Accident reduction factors due to increasing pole density for various levels of traffic volume and pole offsets (Continued).

ADT LEVEL 5000. POLE OFFSET 3. FEET

POLE DENSITY BEFORE IMPROVEMENT (POLES/MILE)	POLE DENSITY AFTER IMPROVEMENT (POLES/MILE) 10.	20.	30.	40.	50.	60.	70.
20.	32.	-	-	-	-	-	-
30.	48.	24.	-	-	-	-	-
40.	58.	39.	19.	-	-	-	-
50.	65.	49.	32.	16.	-	-	-
60.	70.	56.	42.	28.	14.	-	-
70.	74.	61.	49.	37.	25.	12.	-
80.	76.	66.	55.	44.	33.	22.	11.
90.	79.	69.	59.	49.	39.	30.	20.

ADT LEVEL 5000. POLE OFFSET 15. FEET

POLE DENSITY BEFORE IMPROVEMENT (POLES/MILE)	POLE DENSITY AFTER IMPROVEMENT (POLES/MILE) 10.	20.	30.	40.	50.	60.	70.
20.	36.	-	-	-	-	-	-
30.	53.	26.	-	-	-	-	-
40.	63.	42.	21.	-	-	-	-
50.	69.	52.	35.	17.	-	-	-
60.	74.	59.	44.	29.	15.	-	-
70.	77.	64.	51.	39.	26.	13.	-
80.	80.	68.	57.	46.	34.	23.	11.
90.	82.	72.	61.	51.	41.	31.	20.

ADT LEVEL 5000. POLE OFFSET 7. FEET

POLE DENSITY BEFORE IMPROVEMENT (POLES/MILE)	POLE DENSITY AFTER IMPROVEMENT (POLES/MILE) 10.	20.	30.	40.	50.	60.	70.
20.	33.	-	-	-	-	-	-
30.	50.	25.	-	-	-	-	-
40.	60.	40.	20.	-	-	-	-
50.	67.	50.	33.	17.	-	-	-
60.	71.	57.	43.	29.	14.	-	-
70.	75.	62.	50.	37.	25.	12.	-
80.	78.	67.	56.	44.	33.	22.	11.
90.	80.	70.	60.	50.	40.	30.	20.

ADT LEVEL 5000. POLE OFFSET 25. FEET

POLE DENSITY BEFORE IMPROVEMENT (POLES/MILE)	POLE DENSITY AFTER IMPROVEMENT (POLES/MILE) 10.	20.	30.	40.	50.	60.	70.
20.	39.	-	-	-	-	-	-
30.	56.	28.	-	-	-	-	-
40.	66.	44.	22.	-	-	-	-
50.	72.	54.	36.	18.	-	-	-
60.	76.	61.	46.	30.	15.	-	-
70.	79.	66.	53.	40.	26.	13.	-
80.	82.	70.	58.	47.	35.	23.	12.
90.	84.	73.	63.	52.	42.	31.	21.

Table 28. Accident reduction factors due to increasing pole density for various levels of traffic volume and pole offsets (Continued).

ADT LEVEL 10000. POLE OFFSET 3. FEET

POLE DENSITY BEFORE IMPROVEMENT (POLES/MILE)	POLE DENSITY AFTER IMPROVEMENT (POLES/MILE)						
	10.	20.	30.	40.	50.	60.	70.
20.	22.	-	-	-	-	-	-
30.	36.	18.	-	-	-	-	-
40.	46.	31.	15.	-	-	-	-
50.	53.	40.	27.	13.	-	-	-
60.	58.	47.	35.	23.	12.	-	-
70.	63.	52.	42.	31.	21.	10.	-
80.	66.	57.	47.	38.	28.	19.	9.
90.	69.	61.	52.	43.	35.	26.	17.

ADT LEVEL 10000. POLE OFFSET 15. FEET

POLE DENSITY BEFORE IMPROVEMENT (POLES/MILE)	POLE DENSITY AFTER IMPROVEMENT (POLES/MILE)						
	10.	20.	30.	40.	50.	60.	70.
20.	24.	-	-	-	-	-	-
30.	39.	19.	-	-	-	-	-
40.	49.	32.	16.	-	-	-	-
50.	56.	42.	28.	14.	-	-	-
60.	61.	49.	37.	24.	12.	-	-
70.	65.	54.	44.	33.	22.	11.	-
80.	69.	59.	49.	39.	29.	20.	10.
90.	72.	63.	54.	45.	36.	27.	18.

ADT LEVEL 10000. POLE OFFSET 7. FEET

POLE DENSITY BEFORE IMPROVEMENT (POLES/MILE)	POLE DENSITY AFTER IMPROVEMENT (POLES/MILE)						
	10.	20.	30.	40.	50.	60.	70.
20.	23.	-	-	-	-	-	-
30.	37.	19.	-	-	-	-	-
40.	47.	31.	16.	-	-	-	-
50.	54.	41.	27.	14.	-	-	-
60.	60.	48.	36.	24.	12.	-	-
70.	64.	53.	43.	32.	21.	11.	-
80.	67.	58.	48.	38.	29.	19.	10.
90.	70.	61.	53.	44.	35.	26.	18.

ADT LEVEL 10000. POLE OFFSET 25. FEET

POLE DENSITY BEFORE IMPROVEMENT (POLES/MILE)	POLE DENSITY AFTER IMPROVEMENT (POLES/MILE)						
	10.	20.	30.	40.	50.	60.	70.
20.	25.	-	-	-	-	-	-
30.	40.	20.	-	-	-	-	-
40.	50.	34.	17.	-	-	-	-
50.	57.	43.	29.	14.	-	-	-
60.	63.	50.	38.	25.	13.	-	-
70.	67.	56.	45.	33.	22.	11.	-
80.	70.	60.	50.	40.	30.	20.	10.
90.	73.	64.	55.	46.	36.	27.	18.

Table 28. Accident reduction factors due to increasing pole density for various levels of traffic volume and pole offsets (Continued).

ADT LEVEL 15000. POLE OFFSET 3. FEET

POLE DENSITY BEFORE IMPROVEMENT (POLES/MILE)	POLE DENSITY AFTER IMPROVEMENT (POLES/MILE) 10.	20.	30.	40.	50.	60.	70.
20.	17.	-	-	-	-	-	-
30.	29.	14.	-	-	-	-	-
40.	38.	25.	13.	-	-	-	-
50.	45.	34.	22.	11.	-	-	-
60.	50.	40.	30.	20.	10.	-	-
70.	55.	46.	37.	27.	18.	9.	-
80.	59.	50.	42.	34.	25.	17.	8.
90.	62.	54.	46.	39.	31.	23.	15.

ADT LEVEL 15000. POLE OFFSET 15. FEET

POLE DENSITY BEFORE IMPROVEMENT (POLES/MILE)	POLE DENSITY AFTER IMPROVEMENT (POLES/MILE) 10.	20.	30.	40.	50.	60.	70.
20.	18.	-	-	-	-	-	-
30.	30.	15.	-	-	-	-	-
40.	40.	26.	13.	-	-	-	-
50.	47.	35.	23.	12.	-	-	-
60.	52.	42.	31.	21.	10.	-	-
70.	57.	47.	38.	28.	19.	9.	-
80.	61.	52.	43.	35.	26.	17.	9.
90.	64.	56.	48.	40.	32.	24.	16.

ADT LEVEL 15000. POLE OFFSET 7. FEET

POLE DENSITY BEFORE IMPROVEMENT (POLES/MILE)	POLE DENSITY AFTER IMPROVEMENT (POLES/MILE) 10.	20.	30.	40.	50.	60.	70.
20.	17.	-	-	-	-	-	-
30.	29.	15.	-	-	-	-	-
40.	39.	26.	13.	-	-	-	-
50.	46.	34.	23.	11.	-	-	-
60.	51.	41.	31.	20.	10.	-	-
70.	56.	46.	37.	28.	19.	9.	-
80.	59.	51.	42.	34.	25.	17.	8.
90.	63.	55.	47.	39.	31.	23.	16.

ADT LEVEL 15000. POLE OFFSET 25. FEET

POLE DENSITY BEFORE IMPROVEMENT (POLES/MILE)	POLE DENSITY AFTER IMPROVEMENT (POLES/MILE) 10.	20.	30.	40.	50.	60.	70.
20.	19.	-	-	-	-	-	-
30.	32.	16.	-	-	-	-	-
40.	41.	27.	14.	-	-	-	-
50.	48.	36.	24.	12.	-	-	-
60.	53.	43.	32.	21.	11.	-	-
70.	58.	48.	39.	29.	19.	10.	-
80.	62.	53.	44.	35.	26.	18.	9.
90.	65.	57.	49.	40.	32.	24.	16.

Table 28. Accident reduction factors due to increasing pole density for various levels of traffic volume and pole offsets (Continued).

ADT LEVEL 25000. POLE OFFSET 3. FEET

POLE DENSITY BEFORE IMPROVEMENT (POLES/MILE)	POLE DENSITY AFTER IMPROVEMENT (POLES/MILE)						
	10.	20.	30.	40.	50.	60.	70.
20.	11.	-	-	-	-	-	-
30.	21.	10.	-	-	-	-	-
40.	28.	19.	9.	-	-	-	-
50.	34.	26.	17.	9.	-	-	-
60.	39.	31.	24.	16.	8.	-	-
70.	44.	36.	29.	22.	15.	7.	-
80.	48.	41.	34.	27.	20.	14.	7.
90.	51.	45.	38.	32.	25.	19.	13.

ADT LEVEL 25000. POLE OFFSET 15. FEET

POLE DENSITY BEFORE IMPROVEMENT (POLES/MILE)	POLE DENSITY AFTER IMPROVEMENT (POLES/MILE)						
	10.	20.	30.	40.	50.	60.	70.
20.	12.	-	-	-	-	-	-
30.	21.	11.	-	-	-	-	-
40.	29.	19.	10.	-	-	-	-
50.	35.	26.	18.	9.	-	-	-
60.	41.	32.	24.	16.	8.	-	-
70.	45.	37.	30.	22.	15.	7.	-
80.	49.	42.	35.	28.	21.	14.	7.
90.	52.	46.	39.	33.	26.	20.	13.

ADT LEVEL 25000. POLE OFFSET 7. FEET

POLE DENSITY BEFORE IMPROVEMENT (POLES/MILE)	POLE DENSITY AFTER IMPROVEMENT (POLES/MILE)						
	10.	20.	30.	40.	50.	60.	70.
20.	12.	-	-	-	-	-	-
30.	21.	10.	-	-	-	-	-
40.	28.	19.	9.	-	-	-	-
50.	35.	26.	17.	9.	-	-	-
60.	40.	32.	24.	16.	8.	-	-
70.	44.	37.	30.	22.	15.	7.	-
80.	48.	41.	34.	27.	21.	14.	7.
90.	51.	45.	39.	32.	26.	19.	13.

ADT LEVEL 25000. POLE OFFSET 25. FEET

POLE DENSITY BEFORE IMPROVEMENT (POLES/MILE)	POLE DENSITY AFTER IMPROVEMENT (POLES/MILE)						
	10.	20.	30.	40.	50.	60.	70.
20.	12.	-	-	-	-	-	-
30.	22.	11.	-	-	-	-	-
40.	30.	20.	10.	-	-	-	-
50.	36.	27.	18.	9.	-	-	-
60.	41.	33.	25.	16.	8.	-	-
70.	46.	38.	30.	23.	15.	8.	-
80.	50.	42.	35.	28.	21.	14.	7.
90.	53.	46.	40.	33.	26.	20.	13.

Table 28. Accident reduction factors due to increasing pole density for various levels of traffic volume and pole offsets (Continued).

ADT LEVEL 40000. POLE OFFSET 3. FEET

POLE DENSITY BEFORE IMPROVEMENT (POLES/MILE)	POLE DENSITY AFTER IMPROVEMENT (POLES/MILE)						
	10.	20.	30.	40.	50.	60.	70.
20.	8.	-	-	-	-	-	-
30.	14.	7.	-	-	-	-	-
40.	20.	13.	7.	-	-	-	-
50.	25.	19.	13.	6.	-	-	-
60.	30.	24.	18.	12.	6.	-	-
70.	34.	28.	22.	17.	11.	6.	-
80.	37.	32.	26.	21.	16.	11.	5.
90.	40.	35.	30.	25.	20.	15.	10.

ADT LEVEL 40000. POLE OFFSET 15. FEET

POLE DENSITY BEFORE IMPROVEMENT (POLES/MILE)	POLE DENSITY AFTER IMPROVEMENT (POLES/MILE)						
	10.	20.	30.	40.	50.	60.	70.
20.	8.	-	-	-	-	-	-
30.	15.	7.	-	-	-	-	-
40.	21.	14.	7.	-	-	-	-
50.	26.	19.	13.	6.	-	-	-
60.	30.	24.	18.	12.	6.	-	-
70.	34.	29.	23.	17.	11.	6.	-
80.	38.	32.	27.	22.	16.	11.	5.
90.	41.	36.	31.	26.	21.	15.	10.

ADT LEVEL 40000. POLE OFFSET 7. FEET

POLE DENSITY BEFORE IMPROVEMENT (POLES/MILE)	POLE DENSITY AFTER IMPROVEMENT (POLES/MILE)						
	10.	20.	30.	40.	50.	60.	70.
20.	8.	-	-	-	-	-	-
30.	15.	7.	-	-	-	-	-
40.	20.	14.	7.	-	-	-	-
50.	25.	19.	13.	6.	-	-	-
60.	30.	24.	18.	12.	6.	-	-
70.	34.	28.	23.	17.	11.	6.	-
80.	37.	32.	27.	21.	16.	11.	5.
90.	41.	35.	30.	25.	20.	15.	10.

ADT LEVEL 40000. POLE OFFSET 25. FEET

POLE DENSITY BEFORE IMPROVEMENT (POLES/MILE)	POLE DENSITY AFTER IMPROVEMENT (POLES/MILE)						
	10.	20.	30.	40.	50.	60.	70.
20.	8.	-	-	-	-	-	-
30.	15.	8.	-	-	-	-	-
40.	21.	14.	7.	-	-	-	-
50.	26.	20.	13.	7.	-	-	-
60.	31.	25.	18.	12.	6.	-	-
70.	35.	29.	23.	17.	12.	6.	-
80.	38.	33.	27.	22.	16.	11.	5.
90.	41.	36.	31.	26.	21.	16.	10.

Table 28. Accident reduction factors due to increasing pole density for various levels of traffic volume and pole offsets (Continued).

ADT LEVEL 60000. POLE OFFSET 3. FEET

POLE DENSITY BEFORE IMPROVEMENT (POLES/MILE)	POLE DENSITY AFTER IMPROVEMENT (POLES/MILE)						
	10.	20.	30.	40.	50.	60.	70.
20.	5.	-	-	-	-	-	-
30.	10.	5.	-	-	-	-	-
40.	15.	10.	5.	-	-	-	-
50.	19.	14.	9.	5.	-	-	-
60.	22.	18.	13.	9.	4.	-	-
70.	26.	21.	17.	13.	9.	4.	-
80.	29.	25.	20.	16.	12.	8.	4.
90.	31.	28.	24.	20.	16.	12.	8.

ADT LEVEL 60000. POLE OFFSET 15. FEET

POLE DENSITY BEFORE IMPROVEMENT (POLES/MILE)	POLE DENSITY AFTER IMPROVEMENT (POLES/MILE)						
	10.	20.	30.	40.	50.	60.	70.
20.	6.	-	-	-	-	-	-
30.	10.	5.	-	-	-	-	-
40.	15.	10.	5.	-	-	-	-
50.	19.	14.	9.	5.	-	-	-
60.	23.	18.	14.	9.	5.	-	-
70.	26.	22.	17.	13.	9.	4.	-
80.	29.	25.	21.	17.	12.	8.	4.
90.	32.	28.	24.	20.	16.	12.	8.

ADT LEVEL 60000. POLE OFFSET 7. FEET

POLE DENSITY BEFORE IMPROVEMENT (POLES/MILE)	POLE DENSITY AFTER IMPROVEMENT (POLES/MILE)						
	10.	20.	30.	40.	50.	60.	70.
20.	5.	-	-	-	-	-	-
30.	10.	5.	-	-	-	-	-
40.	15.	10.	5.	-	-	-	-
50.	19.	14.	9.	5.	-	-	-
60.	22.	18.	13.	9.	4.	-	-
70.	26.	21.	17.	13.	9.	4.	-
80.	29.	25.	21.	16.	12.	8.	4.
90.	32.	28.	24.	20.	16.	12.	8.

ADT LEVEL 60000. POLE OFFSET 25. FEET

POLE DENSITY BEFORE IMPROVEMENT (POLES/MILE)	POLE DENSITY AFTER IMPROVEMENT (POLES/MILE)						
	10.	20.	30.	40.	50.	60.	70.
20.	6.	-	-	-	-	-	-
30.	11.	5.	-	-	-	-	-
40.	15.	10.	5.	-	-	-	-
50.	19.	14.	10.	5.	-	-	-
60.	23.	18.	14.	9.	5.	-	-
70.	26.	22.	18.	13.	9.	4.	-
80.	29.	25.	21.	17.	13.	8.	4.
90.	32.	28.	24.	20.	16.	12.	8.

APPENDIX C - EXPECTED NUMBER OF UTILITY POLE ACCIDENTS REDUCED

The predictive model was used to compute expected utility pole accidents per mile (1.6 km) per year for various combinations of pole offset, traffic volume, and pole density, as given in table 19. Accident reduction factors were computed from the predictive model due to reducing pole density or for increasing pole offset, as given in Appendix B. Based on this information, computations were then made for the reduction in the number of the utility pole accidents which would be expected due to increasing lateral pole offset or reducing pole density under a variety of conditions.

Increasing Lateral Pole Offset

Table 29 provides estimates of the number of utility pole accidents which are expected to be reduced due to moving poles further from the roadway. For example, the table corresponding to a roadway with a traffic volume of 5,000 and 75 poles per mile (47 poles/km). By increasing the offsets of poles from 4 feet to 17 feet (1.2 to 5.2 m), a reduction of 0.80 utility pole accidents might be expected (on the average) per mile (1.6 km) per year. Thus, for a 3 mile (4.8 km) section, a reduction of about 3 x 0.8 = 2.4 utility pole accidents per year may be expected on the section.

Reducing Pole Densities

Table 30 provide estimates of the reduction in utility pole accidents which should result due to reducing the number of poles. For example, consider the table corresponding to an traffic volume of 10,000 with pole offsets of 7 feet (2.1 m). If utility pole density is reduced from 70 poles per mile (44 poles/km) to 50 poles per mile (31 poles/km) due to increasing pole spacings, an estimated 0.22 utility pole accidents are expected to be reduced per mile (1.6 km) per year.

The values in tables 29 and 30 assume that utility pole accidents follow an average or expected pattern for given levels of traffic volume, pole offset, and pole density, as computed from the predictive model. For a roadway section with an abnormally high or low incidence of utility pole accidents, values in these tables may not apply.

Table 29. Expected number of utility pole accidents reduced due to increasing lateral pole offsets.

ADT LEVEL 1000. POLE DENSITY 20. POLES/MILE

POLE OFFSET BEFORE IMPROVEMENT (FEET)	POLE OFFSET AFTER IMPROVEMENT (FEET) 6.	8.	10.	12.	15.	17.	20.	25.	30.
2.	0.26	0.30	0.33	0.35	0.37	0.39	0.40	0.42	0.43
3.	0.14	0.19	0.21	0.24	0.26	0.27	0.28	0.30	0.31
4.	0.08	0.12	0.15	0.17	0.19	0.20	0.22	0.23	0.25
5.	0.03	0.08	0.10	0.13	0.15	0.16	0.17	0.19	0.20
6.	-	0.04	0.07	0.09	0.12	0.13	0.14	0.16	0.17
7.	-	0.02	0.05	0.07	0.09	0.10	0.12	0.13	0.15
8.	-	-	0.03	0.05	0.07	0.08	0.10	0.11	0.13
9.	-	-	0.01	0.03	0.06	0.07	0.08	0.10	0.11
10.	-	-	-	0.02	0.04	0.06	0.07	0.09	0.10
11.	-	-	-	0.01	0.03	0.04	0.06	0.07	0.09
12.	-	-	-	-	0.02	0.03	0.05	0.06	0.08
13.	-	-	-	-	0.01	0.03	0.04	0.06	0.07
14.	-	-	-	-	0.01	0.02	0.03	0.05	0.06
15.	-	-	-	-	-	0.01	0.03	0.04	0.05

ADT LEVEL 1000. POLE DENSITY 40. POLES/MILE

POLE OFFSET BEFORE IMPROVEMENT (FEET)	POLE OFFSET AFTER IMPRDVEMENT (FEET) 6.	8.	10.	12.	15.	17.	20.	25.	30.
2.	0.48	0.56	0.62	0.66	0.70	0.72	0.75	0.78	0.80
3.	0.27	0.35	0.40	0.44	0.49	0.51	0.53	0.56	0.59
4.	0.14	0.22	0.28	0.32	0.36	0.38	0.41	0.44	0.46
5.	0.06	0.14	0.20	0.24	0.28	0.30	0.33	0.36	0.38
6.	-	0.08	0.14	0.18	0.22	0.24	0.27	0.30	0.32
7.	-	0.04	0.09	0.13	0.17	0.19	0.22	0.25	0.27
8.	-	-	0.05	0.09	0.14	0.16	0.18	0.22	0.24
9.	-	-	0.02	0.06	0.11	0.13	0.15	0.19	0.21
10.	-	-	-	0.04	0.08	0.10	0.13	0.16	0.18
11.	-	-	-	0.02	0.06	0.08	0.11	0.14	0.16
12.	-	-	-	-	0.04	0.06	0.09	0.12	0.14
13.	-	-	-	-	0.03	0.05	0.07	0.11	0.13
14.	-	-	-	-	0.01	0.03	0.06	0.09	0.11
15.	-	-	-	-	-	0.02	0.05	0.08	0.10

ADT LEVEL 1000. POLE DENSITY 75. POLES/MILE

POLE OFFSET BEFORE IMPROVEMENT (FEET)	POLE OFFSET AFTER IMPROVEMENT (FEET) 6.	8.	10.	12.	15.	17.	20.	25.	30.
2.	0.88	1.03	1.13	1.20	1.28	1.31	1.36	1.42	1.46
3.	0.49	0.63	0.73	0.81	0.88	0.92	0.97	1.03	1.07
4.	0.26	0.41	0.51	0.58	0.66	0.70	0.74	0.80	0.84
5.	0.11	0.26	0.36	0.43	0.51	0.55	0.59	0.65	0.69
6.	-	0.15	0.25	0.32	0.40	0.44	0.48	0.54	0.58
7.	-	0.07	0.17	0.24	0.31	0.35	0.40	0.46	0.50
8.	-	-	0.10	0.17	0.25	0.29	0.33	0.39	0.43
9.	-	-	0.05	0.12	0.19	0.23	0.28	0.34	0.38
10.	-	-	-	0.07	0.15	0.19	0.24	0.29	0.33
11.	-	-	-	0.03	0.11	0.15	0.20	0.25	0.30
12.	-	-	-	-	0.08	0.12	0.16	0.22	0.26
13.	-	-	-	-	0.05	0.09	0.13	0.19	0.23
14.	-	-	-	-	0.02	0.06	0.11	0.17	0.21
15.	-	-	-	-	-	0.04	0.09	0.14	0.18

Table 29. Expected number of utility pole accidents reduced due to increasing lateral pole offsets (Continued).

ADT LEVEL 5000. POLE DENSITY 20. POLES/MILE

POLE OFFSET BEFORE IMPROVEMENT (FEET)	POLE OFFSET AFTER IMPROVEMENT (FEET)								
	6.	8.	10.	12.	15.	17.	20.	25.	30.
2.	0.38	0.45	0.49	0.52	0.56	0.57	0.59	0.62	0.64
3.	0.21	0.28	0.32	0.35	0.38	0.40	0.42	0.45	0.47
4.	0.11	0.18	0.22	0.25	0.29	0.30	0.32	0.35	0.37
5.	0.05	0.11	0.16	0.19	0.22	0.24	0.26	0.28	0.30
6.	-	0.06	0.11	0.14	0.17	0.19	0.21	0.24	0.25
7.	-	0.03	0.07	0.10	0.14	0.15	0.17	0.20	0.22
8.	-	-	0.04	0.07	0.11	0.13	0.15	0.17	0.19
9.	-	-	0.02	0.05	0.08	0.10	0.12	0.15	0.17
10.	-	-	-	0.03	0.07	0.08	0.10	0.13	0.15
11.	-	-	-	0.01	0.05	0.07	0.09	0.11	0.13
12.	-	-	-	-	0.03	0.05	0.07	0.10	0.11
13.	-	-	-	-	0.02	0.04	0.06	0.08	0.10
14.	-	-	-	-	0.01	0.03	0.05	0.07	0.09
15.	-	-	-	-	-	0.02	0.04	0.06	0.08

ADT LEVEL 5000. POLE DENSITY 40. POLES/MILE

POLE OFFSET BEFORE IMPROVEMENT (FEET)	POLE OFFSET AFTER IMPROVEMENT (FEET)								
	6.	8.	10.	12.	15.	17.	20.	25.	30.
2.	0.61	0.71	0.78	0.83	0.88	0.91	0.94	0.98	1.01
3.	0.34	0.44	0.51	0.56	0.61	0.64	0.67	0.71	0.74
4.	0.18	0.28	0.35	0.40	0.46	0.48	0.51	0.55	0.58
5.	0.08	0.18	0.25	0.30	0.35	0.38	0.41	0.45	0.48
6.	-	0.10	0.17	0.22	0.28	0.30	0.34	0.37	0.40
7.	-	0.05	0.11	0.16	0.22	0.25	0.28	0.32	0.35
8.	-	-	0.07	0.12	0.17	0.20	0.23	0.27	0.30
9.	-	-	0.03	0.08	0.13	0.16	0.19	0.23	0.26
10.	-	-	-	0.05	0.10	0.13	0.16	0.20	0.23
11.	-	-	-	0.02	0.08	0.10	0.14	0.18	0.20
12.	-	-	-	-	0.05	0.08	0.11	0.15	0.18
13.	-	-	-	-	0.03	0.06	0.09	0.13	0.16
14.	-	-	-	-	0.02	0.04	0.08	0.12	0.14
15.	-	-	-	-	-	0.03	0.06	0.10	0.13

ADT LEVEL 5000. POLE DENSITY 75. POLES/MILE

POLE OFFSET BEFORE IMPROVEMENT (FEET)	POLE OFFSET AFTER IMPROVEMENT (FEET)								
	6.	8.	10.	12.	15.	17.	20.	25.	30.
2.	1.00	1.17	1.29	1.37	1.46	1.50	1.56	1.62	1.67
3.	0.55	0.72	0.84	0.92	1.01	1.05	1.11	1.17	1.22
4.	0.30	0.47	0.58	0.66	0.75	0.80	0.85	0.91	0.96
5.	0.12	0.29	0.41	0.49	0.58	0.62	0.68	0.74	0.79
6.	-	0.17	0.28	0.37	0.45	0.50	0.55	0.62	0.67
7.	-	0.08	0.19	0.27	0.36	0.40	0.46	0.52	0.57
8.	-	-	0.11	0.20	0.28	0.33	0.38	0.45	0.50
8.	-	-	0.05	0.13	0.22	0.27	0.32	0.39	0.43
10.	-	-	-	0.08	0.17	0.22	0.27	0.33	0.38
11.	-	-	-	0.04	0.13	0.17	0.23	0.29	0.34
12.	-	-	-	-	0.09	0.13	0.19	0.25	0.30
13.	-	-	-	-	0.06	0.10	0.15	0.22	0.27
14.	-	-	-	-	0.03	0.07	0.12	0.19	0.24
15.	-	-	-	-	-	0.04	0.10	0.16	0.21

Table 29. Expected number of utility pole accidents reduced due to increasing lateral pole offsets (Continued).

ADT LEVEL 10000. POLE DENSITY 20. POLES/MILE

POLE OFFSET BEFORE IMPROVEMENT (FEET)	POLE OFFSET AFTER IMPROVEMENT (FEET)								
	6.	8.	10.	12.	15.	17.	20.	25.	30.
2.	0.54	0.63	0.69	0.74	0.78	0.81	0.84	0.87	0.90
3.	0.30	0.39	0.45	0.49	0.54	0.57	0.60	0.63	0.66
4.	0.16	0.25	0.31	0.36	0.40	0.43	0.46	0.49	0.52
5.	0.07	0.16	0.22	0.26	0.31	0.34	0.36	0.40	0.42
6.	-	0.09	0.15	0.20	0.24	0.27	0.30	0.33	0.36
7.	-	0.04	0.10	0.15	0.19	0.22	0.25	0.28	0.31
8.	-	-	0.06	0.10	0.15	0.18	0.21	0.24	0.27
9.	-	-	0.03	0.07	0.12	0.14	0.17	0.21	0.23
10.	-	-	-	0.04	0.09	0.12	0.14	0.18	0.21
11.	-	-	-	0.02	0.07	0.09	0.12	0.16	0.18
12.	-	-	-	-	0.05	0.07	0.10	0.14	0.16
13.	-	-	-	-	0.03	0.05	0.08	0.12	0.14
14.	-	-	-	-	0.01	0.04	0.07	0.10	0.13
15.	-	-	-	-	-	0.02	0.05	0.09	0.11

ADT LEVEL 10000. POLE DENSITY 40. POLES/MILE

POLE OFFSET BEFORE IMPROVEMENT (FEET)	POLE OFFSET AFTER IMPROVEMENT (FEET)								
	6.	8.	10.	12.	15.	17.	20.	25.	30.
2.	0.76	0.89	0.98	1.04	1.11	1.15	1.19	1.24	1.27
3.	0.42	0.55	0.64	0.70	0.77	0.80	0.84	0.89	0.93
4.	0.23	0.36	0.44	0.50	0.57	0.61	0.65	0.70	0.73
5.	0.09	0.22	0.31	0.37	0.44	0.48	0.52	0.57	0.60
6.	-	0.13	0.22	0.28	0.35	0.38	0.42	0.47	0.51
7.	-	0.06	0.14	0.21	0.27	0.31	0.35	0.40	0.44
8.	-	-	0.09	0.15	0.22	0.25	0.29	0.34	0.38
9.	-	-	0.04	0.10	0.17	0.20	0.24	0.29	0.33
10.	-	-	-	0.06	0.13	0.16	0.21	0.26	0.29
11.	-	-	-	0.03	0.10	0.13	0.17	0.22	0.26
12.	-	-	-	-	0.07	0.10	0.14	0.19	0.23
13.	-	-	-	-	0.04	0.08	0.12	0.17	0.20
14.	-	-	-	-	0.02	0.05	0.09	0.14	0.18
15.	-	-	-	-	-	0.03	0.07	0.12	0.16

ADT LEVEL 10000. POLE DENSITY 75. POLES/MILE

POLE OFFSET BEFORE IMPROVEMENT (FEET)	POLE OFFSET AFTER IMPROVEMENT (FEET)								
	6.	8.	10.	12.	15.	17.	20.	25.	30.
2.	1.16	1.36	1.49	1.58	1.69	1.74	1.80	1.87	1.93
3.	0.64	0.84	0.97	1.06	1.17	1.22	1.28	1.36	1.41
4.	0.34	0.54	0.67	0.77	0.87	0.92	0.98	1.06	1.11
5.	0.14	0.34	0.47	0.57	0.67	0.72	0.78	0.86	0.91
6.	-	0.20	0.33	0.42	0.53	0.58	0.64	0.71	0.77
7.	-	0.09	0.22	0.31	0.42	0.47	0.53	0.61	0.66
8.	-	-	0.13	0.23	0.33	0.38	0.44	0.52	0.57
9.	-	-	0.06	0.15	0.26	0.31	0.37	0.45	0.50
10.	-	-	-	0.09	0.20	0.25	0.31	0.39	0.44
11.	-	-	-	0.04	0.15	0.20	0.26	0.34	0.39
12.	-	-	-	-	0.10	0.15	0.22	0.29	0.35
13.	-	-	-	-	0.06	0.12	0.18	0.25	0.31
14.	-	-	-	-	0.03	0.08	0.14	0.22	0.27
15.	-	-	-	-	-	0.05	0.11	0.19	0.24

Table 29. Expected number of utility pole accidents reduced due to increasing lateral pole offsets (Continued).

ADT LEVEL 15000. POLE DENSITY 20. POLES/MILE

POLE OFFSET BEFORE IMPROVEMENT (FEET)	POLE OFFSET AFTER IMPROVEMENT (FEET)								
	6.	8.	10.	12.	15.	17.	20.	25.	30.
2.	0.70	0.81	0.89	0.95	1.01	1.04	1.08	1.12	1.16
3.	0.38	0.50	0.58	0.64	0.70	0.73	0.77	0.81	0.85
4.	0.21	0.32	0.40	0.46	0.52	0.55	0.59	0.63	0.67
5.	0.09	0.20	0.28	0.34	0.40	0.43	0.47	0.52	0.55
6.	-	0.12	0.20	0.25	0.32	0.35	0.38	0.43	0.46
7.	-	0.05	0.13	0.19	0.25	0.28	0.32	0.36	0.40
8.	-	-	0.08	0.14	0.20	0.23	0.27	0.31	0.34
9.	-	-	0.04	0.09	0.15	0.19	0.22	0.27	0.30
10.	-	-	-	0.06	0.12	0.15	0.19	0.23	0.26
11.	-	-	-	0.03	0.09	0.12	0.16	0.20	0.23
12.	-	-	-	-	0.06	0.09	0.13	0.18	0.21
13.	-	-	-	-	0.04	0.07	0.11	0.15	0.18
14.	-	-	-	-	0.02	0.05	0.09	0.13	0.16
15.	-	-	-	-	-	0.03	0.07	0.11	0.15

ADT LEVEL 15000. POLE DENSITY 40. POLES/MILE

POLE OFFSET BEFORE IMPROVEMENT (FEET)	POLE OFFSET AFTER IMPROVEMENT (FEET)								
	6.	8.	10.	12.	15.	17.	20.	25.	30.
2.	0.92	1.08	1.18	1.26	1.34	1.38	1.43	1.49	1.53
3.	0.51	0.67	0.77	0.85	0.93	0.97	1.02	1.08	1.12
4.	0.27	0.43	0.53	0.61	0.69	0.73	0.78	0.84	0.88
5.	0.11	0.27	0.37	0.45	0.53	0.57	0.62	0.68	0.73
6.	-	0.16	0.26	0.34	0.42	0.46	0.51	0.57	0.61
7.	-	0.07	0.17	0.25	0.33	0.37	0.42	0.48	0.52
8.	-	-	0.10	0.18	0.26	0.30	0.35	0.41	0.45
9.	-	-	0.05	0.12	0.20	0.25	0.29	0.35	0.40
10.	-	-	-	0.08	0.16	0.20	0.25	0.31	0.35
11.	-	-	-	0.03	0.12	0.16	0.21	0.27	0.31
12.	-	-	-	-	0.08	0.12	0.17	0.23	0.28
13.	-	-	-	-	0.05	0.09	0.14	0.20	0.24
14.	-	-	-	-	0.02	0.07	0.11	0.17	0.22
15.	-	-	-	-	-	0.04	0.09	0.15	0.19

ADT LEVEL 15000. POLE DENSITY 75. POLES/MILE

POLE OFFSET BEFORE IMPROVEMENT (FEET)	POLE OFFSET AFTER IMPROVEMENT (FEET)								
	6.	8.	10.	12.	15.	17.	20.	25.	30.
2.	1.32	1.54	1.69	1.80	1.91	1.97	2.04	2.13	2.19
3.	0.73	0.95	1.10	1.21	1.32	1.38	1.45	1.54	1.60
4.	0.39	0.61	0.76	0.87	0.99	1.04	1.11	1.20	1.26
5.	0.16	0.39	0.54	0.64	0.76	0.82	0.89	0.97	1.04
6.	-	0.22	0.37	0.48	0.60	0.66	0.73	0.81	0.87
7.	-	0.10	0.25	0.36	0.47	0.53	0.60	0.69	0.75
8.	-	-	0.15	0.26	0.37	0.43	0.50	0.59	0.65
9.	-	-	0.07	0.18	0.29	0.35	0.42	0.51	0.57
10.	-	-	-	0.11	0.22	0.28	0.35	0.44	0.50
11.	-	-	-	0.05	0.17	0.23	0.30	0.38	0.44
12.	-	-	-	-	0.12	0.18	0.25	0.33	0.39
13.	-	-	-	-	0.07	0.13	0.20	0.29	0.35
14.	-	-	-	-	0.03	0.09	0.16	0.25	0.31
15.	-	-	-	-	-	0.06	0.13	0.21	0.28

Table 29. Expected number of utility pole accidents reduced due to increasing lateral pole offsets (Continued).

ADT LEVEL 25000. POLE DENSITY 20. POLES/MILE

POLE OFFSET BEFORE IMPROVEMENT (FEET)	POLE OFFSET AFTER IMPROVEMENT (FEET)								
	6.	8.	10.	12.	15.	17.	20.	25.	30.
2.	1.01	1.18	1.29	1.38	1.47	1.51	1.57	1.63	1.68
3.	0.56	0.73	0.84	0.93	1.01	1.06	1.11	1.18	1.23
4.	0.30	0.47	0.58	0.67	0.76	0.80	0.85	0.92	0.97
5.	0.12	0.30	0.41	0.49	0.58	0.63	0.68	0.75	0.79
6.	-	0.17	0.29	0.37	0.46	0.50	0.56	0.62	0.67
7.	-	0.08	0.19	0.27	0.36	0.41	0.46	0.53	0.57
8.	-	-	0.11	0.20	0.29	0.33	0.38	0.45	0.50
9.	-	-	0.05	0.13	0.22	0.27	0.32	0.39	0.44
10.	-	-	-	0.08	0.17	0.22	0.27	0.34	0.38
11.	-	-	-	0.04	0.13	0.17	0.23	0.29	0.34
12.	-	-	-	-	0.09	0.13	0.19	0.25	0.30
13.	-	-	-	-	0.06	0.10	0.15	0.22	0.27
14.	-	-	-	-	0.03	0.07	0.13	0.19	0.24
15.	-	-	-	-	-	0.05	0.10	0.16	0.21

ADT LEVEL 25000. POLE DENSITY 40. POLES/MILE

POLE OFFSET BEFORE IMPROVEMENT (FEET)	POLE OFFSET AFTER IMPROVEMENT (FEET)								
	6.	8.	10.	12.	15.	17.	20.	25.	30.
2.	1.23	1.44	1.58	1.68	1.79	1.85	1.92	2.00	2.05
3.	0.68	0.89	1.03	1.13	1.24	1.30	1.36	1.44	1.50
4.	0.36	0.57	0.71	0.81	0.92	0.98	1.05	1.13	1.18
5.	0.15	0.36	0.50	0.60	0.71	0.77	0.83	0.91	0.97
6.	-	0.21	0.35	0.45	0.56	0.61	0.68	0.76	0.82
7.	-	0.09	0.23	0.33	0.44	0.50	0.56	0.64	0.70
8.	-	-	0.14	0.24	0.35	0.41	0.47	0.55	0.61
9.	-	-	0.06	0.16	0.27	0.33	0.39	0.48	0.53
10.	-	-	-	0.10	0.21	0.27	0.33	0.41	0.47
11.	-	-	-	0.05	0.16	0.21	0.28	0.36	0.42
12.	-	-	-	-	0.11	0.16	0.23	0.31	0.37
13.	-	-	-	-	0.07	0.12	0.19	0.27	0.33
14.	-	-	-	-	0.03	0.09	0.15	0.23	0.29
15.	-	-	-	-	-	0.06	0.12	0.20	0.26

ADT LEVEL 25000. POLE DENSITY 75. POLES/MILE

POLE OFFSET BEFORE IMPROVEMENT (FEET)	POLE OFFSET AFTER IMPROVEMENT (FEET)								
	6.	8.	10.	12.	15.	17.	20.	25.	30.
2.	1.63	1.91	2.09	2.22	2.37	2.44	2.53	2.63	2.71
3.	0.90	1.18	1.36	1.49	1.64	1.71	1.80	1.91	1.98
4.	0.48	0.76	0.94	1.08	1.22	1.29	1.38	1.49	1.56
5.	0.20	0.48	0.66	0.80	0.94	1.01	1.10	1.21	1.28
6.	-	0.28	0.46	0.59	0.74	0.81	0.90	1.00	1.08
7.	-	0.12	0.31	0.44	0.58	0.66	0.74	0.85	0.93
8.	-	-	0.18	0.32	0.46	0.53	0.62	0.73	0.80
9.	-	-	0.08	0.22	0.36	0.43	0.52	0.63	0.70
10.	-	-	-	0.13	0.28	0.35	0.44	0.54	0.62
11.	-	-	-	0.06	0.21	0.28	0.37	0.47	0.55
12.	-	-	-	-	0.14	0.22	0.30	0.41	0.49
13.	-	-	-	-	0.09	0.16	0.25	0.36	0.43
14.	-	-	-	-	0.04	0.12	0.20	0.31	0.39
15.	-	-	-	-	-	0.07	0.16	0.27	0.34

Table 29. Expected number of utility pole accidents reduced due to increasing lateral pole offsets (Continued).

ADT LEVEL 40000. POLE DENSITY 20. POLES/MILE

POLE OFFSET BEFORE IMPROVEMENT (FEET)	POLE OFFSET AFTER IMPROVEMENT (FEET)								
	6.	8.	10.	12.	15.	17.	20.	25.	30.
2.	1.48	1.73	1.90	2.02	2.15	2.22	2.29	2.39	2.46
3.	0.82	1.07	1.24	1.36	1.49	1.55	1.63	1.73	1.80
4.	0.44	0.69	0.85	0.98	1.11	1.17	1.25	1.35	1.42
5.	0.18	0.43	0.60	0.72	0.85	0.92	1.00	1.09	1.16
6.	-	0.25	0.42	0.54	0.67	0.74	0.82	0.91	0.98
7.	-	0.11	0.28	0.40	0.53	0.60	0.68	0.77	0.84
8.	-	-	0.17	0.29	0.42	0.49	0.56	0.66	0.73
9.	-	-	0.08	0.20	0.33	0.39	0.47	0.57	0.64
10.	-	-	-	0.12	0.25	0.32	0.40	0.49	0.56
11.	-	-	-	0.06	0.19	0.25	0.33	0.43	0.50
12.	-	-	-	-	0.13	0.20	0.28	0.37	0.44
13.	-	-	-	-	0.08	0.15	0.23	0.32	0.39
14.	-	-	-	-	0.04	0.10	0.18	0.28	0.35
15.	-	-	-	-	-	0.07	0.14	0.24	0.31

ADT LEVEL 40000. POLE DENSITY 40. POLES/MILE

POLE OFFSET BEFORE IMPROVEMENT (FEET)	POLE OFFSET AFTER IMPROVEMENT (FEET)								
	6.	8.	10.	12.	15.	17.	20.	25.	30.
2.	1.70	1.99	2.19	2.33	2.48	2.55	2.64	2.76	2.84
3.	0.94	1.23	1.42	1.56	1.71	1.79	1.88	1.99	2.07
4.	0.50	0.79	0.99	1.12	1.28	1.35	1.44	1.55	1.63
5.	0.21	0.50	0.69	0.83	0.98	1.06	1.15	1.26	1.34
6.	-	0.29	0.48	0.62	0.77	0.85	0.94	1.05	1.13
7.	-	0.13	0.32	0.46	0.61	0.69	0.78	0.89	0.97
8.	-	-	0.19	0.33	0.48	0.56	0.65	0.76	0.84
9.	-	-	0.09	0.23	0.38	0.45	0.55	0.66	0.74
10.	-	-	-	0.14	0.29	0.37	0.46	0.57	0.65
11.	-	-	-	0.06	0.22	0.29	0.38	0.49	0.57
12.	-	-	-	-	0.15	0.23	0.32	0.43	0.51
13.	-	-	-	-	0.09	0.17	0.26	0.37	0.45
14.	-	-	-	-	0.04	0.12	0.21	0.32	0.40
15.	-	-	-	-	-	0.08	0.17	0.28	0.36

ADT LEVEL 40000. POLE DENSITY 75. POLES/MILE

POLE OFFSET BEFORE IMPROVEMENT (FEET)	POLE OFFSET AFTER IMPROVEMENT (FEET)								
	6.	8.	10.	12.	15.	17.	20.	25.	30.
2.	2.10	2.46	2.69	2.87	3.05	3.15	3.26	3.39	3.49
3.	1.16	1.52	1.75	1.93	2.11	2.21	2.32	2.45	2.55
4.	0.62	0.98	1.21	1.39	1.57	1.67	1.78	1.91	2.01
5.	0.26	0.62	0.85	1.03	1.21	1.31	1.42	1.55	1.65
6.	-	0.36	0.59	0.77	0.95	1.05	1.16	1.29	1.39
7.	-	0.16	0.40	0.57	0.75	0.85	0.96	1.10	1.19
8.	-	-	0.24	0.41	0.59	0.69	0.80	0.94	1.04
9.	-	-	0.11	0.28	0.47	0.56	0.67	0.81	0.91
10.	-	-	-	0.17	0.36	0.45	0.56	0.70	0.80
11.	-	-	-	0.08	0.27	0.36	0.47	0.61	0.71
12.	-	-	-	-	0.19	0.28	0.39	0.53	0.63
13.	-	-	-	-	0.12	0.21	0.32	0.46	0.56
14.	-	-	-	-	0.05	0.15	0.26	0.40	0.50
15.	-	-	-	-	-	0.09	0.21	0.34	0.44

Table 29. Expected number of utility pole accidents reduced due to increasing lateral pole offsets (Continued).

ADT LEVEL 60000. POLE DENSITY 20. POLES/MILE

POLE OFFSET BEFORE IMPROVEMENT (FEET)	POLE OFFSET AFTER IMPROVEMENT (FEET)								
	6.	8.	10.	12.	15.	17.	20.	25.	30.
2.	2.11	2.46	2.70	2.87	3.06	3.15	3.27	3.40	3.50
3.	1.16	1.52	1.76	1.93	2.12	2.21	2.32	2.46	2.56
4.	0.62	0.98	1.22	1.39	1.58	1.67	1.78	1.92	2.02
5.	0.26	0.62	0.86	1.03	1.22	1.31	1.42	1.56	1.66
6.	-	0.36	0.60	0.77	0.95	1.05	1.16	1.30	1.40
7.	-	0.16	0.40	0.57	0.75	0.85	0.96	1.10	1.20
8.	-	-	0.24	0.41	0.60	0.69	0.80	0.94	1.04
9.	-	-	0.11	0.28	0.47	0.56	0.67	0.81	0.91
10.	-	-	-	0.17	0.36	0.45	0.57	0.70	0.80
11.	-	-	-	0.08	0.27	0.36	0.47	0.61	0.71
12.	-	-	-	-	0.19	0.28	0.39	0.53	0.63
13.	-	-	-	-	0.12	0.21	0.32	0.46	0.56
14.	-	-	-	-	0.06	0.15	0.26	0.40	0.50
15.	-	-	-	-	-	0.09	0.21	0.34	0.44

ADT LEVEL 60000. POLE DENSITY 40. POLES/MILE

POLE OFFSET BEFORE IMPROVEMENT (FEET)	POLE OFFSET AFTER IMPROVEMENT (FEET)								
	6.	8.	10.	12.	15.	17.	20.	25.	30.
2.	2.33	2.73	2.99	3.18	3.39	3.49	3.62	3.77	3.88
3.	1.29	1.68	1.95	2.14	2.34	2.45	2.57	2.73	2.84
4.	0.69	1.08	1.35	1.54	1.74	1.85	1.97	2.13	2.24
5.	0.29	0.68	0.95	1.14	1.35	1.45	1.57	1.73	1.84
6.	-	0.40	0.66	0.85	1.06	1.16	1.29	1.44	1.55
7.	-	0.18	0.44	0.63	0.84	0.94	1.06	1.22	1.33
8.	-	-	0.26	0.45	0.66	0.76	0.89	1.04	1.15
9.	-	-	0.12	0.31	0.52	0.62	0.75	0.90	1.01
10.	-	-	-	0.19	0.40	0.50	0.63	0.78	0.89
11.	-	-	-	0.09	0.29	0.40	0.52	0.68	0.79
12.	-	-	-	-	0.21	0.31	0.44	0.59	0.70
13.	-	-	-	-	0.13	0.23	0.36	0.51	0.62
14.	-	-	-	-	0.06	0.17	0.29	0.44	0.55
15.	-	-	-	-	-	0.10	0.23	0.38	0.49

ADT LEVEL 60000. POLE DENSITY 75. POLES/MILE

POLE OFFSET BEFORE IMPROVEMENT (FEET)	POLE OFFSET AFTER IMPROVEMENT (FEET)								
	6.	8.	10.	12.	15.	17.	20.	25.	30.
2.	2.73	3.19	3.50	3.72	3.96	4.08	4.23	4.41	4.54
3.	1.51	1.97	2.28	2.50	2.74	2.86	3.01	3.19	3.32
4.	0.80	1.27	1.58	1.80	2.04	2.16	2.31	2.49	2.61
5.	0.34	0.80	1.11	1.33	1.57	1.70	1.84	2.02	2.15
6.	-	0.46	0.77	0.99	1.24	1.36	1.50	1.68	1.81
7.	-	0.21	0.51	0.74	0.98	1.10	1.24	1.42	1.55
8.	-	-	0.31	0.53	0.77	0.89	1.04	1.22	1.35
9.	-	-	0.14	0.36	0.60	0.73	0.87	1.05	1.18
10.	-	-	-	0.22	0.46	0.59	0.73	0.91	1.04
11.	-	-	-	0.10	0.34	0.47	0.61	0.79	0.92
12.	-	-	-	-	0.24	0.36	0.51	0.69	0.82
13.	-	-	-	-	0.15	0.27	0.42	0.60	0.72
14.	-	-	-	-	0.07	0.19	0.34	0.52	0.64
15.	-	-	-	-	-	0.12	0.27	0.45	0.57

Table 30. Expected number of utility pole accidents reduced due to decreasing pole density.

ADT LEVEL 1000. POLE OFFSET 3. FEET

POLE DENSITY BEFORE IMPROVEMENT (POLES/MILE)	POLE DENSITY AFTER IMPROVEMENT (POLES/MILE) 10.	20.	30.	40.	50.	60.	70.
20.	0.18	-	-	-	-	-	-
30.	0.37	0.18	-	-	-	-	-
40.	0.55	0.37	0.18	-	-	-	-
50.	0.73	0.55	0.37	0.18	-	-	-
60.	0.92	0.73	0.55	0.37	0.18	-	-
70.	1.10	0.92	0.73	0.55	0.37	0.18	-
80.	1.28	1.10	0.92	0.73	0.55	0.37	0.18
90.	1.47	1.28	1.10	0.92	0.73	0.55	0.37

ADT LEVEL 1000. POLE OFFSET 7. FEET

POLE DENSITY BEFORE IMPROVEMENT (POLES/MILE)	POLE DENSITY AFTER IMPROVEMENT (POLES/MILE) 10.	20.	30.	40.	50.	60.	70.
20.	0.11	-	-	-	-	-	-
30.	0.22	0.11	-	-	-	-	-
40.	0.33	0.22	0.11	-	-	-	-
50.	0.44	0.33	0.22	0.11	-	-	-
60.	0.55	0.44	0.33	0.22	0.11	-	-
70.	0.66	0.55	0.44	0.33	0.22	0.11	-
80.	0.77	0.66	0.55	0.44	0.33	0.22	0.11
90.	0.88	0.77	0.66	0.55	0.44	0.33	0.22

ADT LEVEL 1000. POLE OFFSET 15. FEET

POLE DENSITY BEFORE IMPROVEMENT (POLES/MILE)	POLE DENSITY AFTER IMPROVEMENT (POLES/MILE) 10.	20.	30.	40.	50.	60.	70.
20.	0.07	-	-	-	-	-	-
30.	0.14	0.07	-	-	-	-	-
40.	0.21	0.14	0.07	-	-	-	-
50.	0.28	0.21	0.14	0.07	-	-	-
60.	0.35	0.28	0.21	0.14	0.07	-	-
70.	0.42	0.35	0.28	0.21	0.14	0.07	-
80.	0.49	0.42	0.35	0.28	0.21	0.14	0.07
90.	0.56	0.49	0.42	0.35	0.28	0.21	0.14

ADT LEVEL 1000. POLE OFFSET 25. FEET

POLE DENSITY BEFORE IMPROVEMENT (POLES/MILE)	POLE DENSITY AFTER IMPROVEMENT (POLES/MILE) 10.	20.	30.	40.	50.	60.	70.
20.	0.05	-	-	-	-	-	-
30.	0.10	0.05	-	-	-	-	-
40.	0.15	0.10	0.05	-	-	-	-
50.	0.21	0.15	0.10	0.05	-	-	-
60.	0.26	0.21	0.15	0.10	0.05	-	-
70.	0.31	0.26	0.21	0.15	0.10	0.05	-
80.	0.36	0.31	0.26	0.21	0.15	0.10	0.05
90.	0.41	0.36	0.31	0.26	0.21	0.15	0.10

Table 30. Expected number of utility pole accidents reduced due to decreasing pole density (Continued).

ADT LEVEL 5000. POLE OFFSET 3. FEET

POLE DENSITY BEFORE IMPROVEMENT (POLES/MILE)	POLE DENSITY AFTER IMPROVEMENT (POLES/MILE)						
	10.	20.	30.	40.	50.	60.	70.
20.	0.18	-	-	-	-	-	-
30.	0.37	0.18	-	-	-	-	-
40.	0.55	0.37	0.18	-	-	-	-
50.	0.73	0.55	0.37	0.18	-	-	-
60.	0.92	0.73	0.55	0.37	0.18	-	-
70.	1.10	0.92	0.73	0.55	0.37	0.18	-
80.	1.28	1.10	0.92	0.73	0.55	0.37	0.18
90.	1.47	1.28	1.10	0.92	0.73	0.55	0.37

ADT LEVEL 5000. POLE OFFSET 15. FEET

POLE DENSITY BEFORE IMPROVEMENT (POLES/MILE)	POLE DENSITY AFTER IMPROVEMENT (POLES/MILE)						
	10.	20.	30.	40.	50.	60.	70.
20.	0.07	-	-	-	-	-	-
30.	0.14	0.07	-	-	-	-	-
40.	0.21	0.14	0.07	-	-	-	-
50.	0.28	0.21	0.14	0.07	-	-	-
60.	0.35	0.28	0.21	0.14	0.07	-	-
70.	0.42	0.35	0.28	0.21	0.14	0.07	-
80.	0.49	0.42	0.35	0.28	0.21	0.14	0.07
90.	0.56	0.49	0.42	0.35	0.28	0.21	0.14

ADT LEVEL 5000. POLE OFFSET 7. FEET

POLE DENSITY BEFORE IMPROVEMENT (POLES/MILE)	POLE DENSITY AFTER IMPROVEMENT (POLES/MILE)						
	10.	20.	30.	40.	50.	60.	70.
20.	0.11	-	-	-	-	-	-
30.	0.22	0.11	-	-	-	-	-
40.	0.33	0.22	0.11	-	-	-	-
50.	0.44	0.33	0.22	0.11	-	-	-
60.	0.55	0.44	0.33	0.22	0.11	-	-
70.	0.66	0.55	0.44	0.33	0.22	0.11	-
80.	0.77	0.66	0.55	0.44	0.33	0.22	0.11
90.	0.88	0.77	0.66	0.55	0.44	0.33	0.22

ADT LEVEL 5000. POLE OFFSET 25. FEET

POLE DENSITY BEFORE IMPROVEMENT (POLES/MILE)	POLE DENSITY AFTER IMPROVEMENT (POLES/MILE)						
	10.	20.	30.	40.	50.	60.	70.
20.	0.05	-	-	-	-	-	-
30.	0.10	0.05	-	-	-	-	-
40.	0.15	0.10	0.05	-	-	-	-
50.	0.21	0.15	0.10	0.05	-	-	-
60.	0.26	0.21	0.15	0.10	0.05	-	-
70.	0.31	0.26	0.21	0.15	0.10	0.05	-
80.	0.36	0.31	0.26	0.21	0.15	0.10	0.05
90.	0.41	0.36	0.31	0.26	0.21	0.15	0.10

Table 30. Expected number of utility pole accidents reduced due to decreasing pole density (Continued).

ADT LEVEL 10000. POLE OFFSET 3. FEET

POLE DENSITY BEFORE IMPROVEMENT (POLES/MILE)	POLE DENSITY AFTER IMPROVEMENT (POLES/MILE)						
	10.	20.	30.	40.	50.	60.	70.
20.	0.18	-	-	-	-	-	-
30.	0.37	0.18	-	-	-	-	-
40.	0.55	0.37	0.18	-	-	-	-
50.	0.73	0.55	0.37	0.18	-	-	-
60.	0.92	0.73	0.55	0.37	0.18	-	-
70.	1.10	0.92	0.73	0.55	0.37	0.18	-
80.	1.28	1.10	0.92	0.73	0.55	0.37	0.18
90.	1.47	1.28	1.10	0.92	0.73	0.55	0.37

ADT LEVEL 10000. POLE OFFSET 7. FEET

POLE DENSITY BEFORE IMPROVEMENT (POLES/MILE)	POLE DENSITY AFTER IMPROVEMENT (POLES/MILE)						
	10.	20.	30.	40.	50.	60.	70.
20.	0.11	-	-	-	-	-	-
30.	0.22	0.11	-	-	-	-	-
40.	0.33	0.22	0.11	-	-	-	-
50.	0.44	0.33	0.22	0.11	-	-	-
60.	0.55	0.44	0.33	0.22	0.11	-	-
70.	0.66	0.55	0.44	0.33	0.22	0.11	-
80.	0.77	0.66	0.55	0.44	0.33	0.22	0.11
90.	0.88	0.77	0.66	0.55	0.44	0.33	0.22

ADT LEVEL 10000. POLE OFFSET 15. FEET

POLE DENSITY BEFORE IMPROVEMENT (POLES/MILE)	POLE DENSITY AFTER IMPROVEMENT (POLES/MILE)						
	10.	20.	30.	40.	50.	60.	70.
20.	0.07	-	-	-	-	-	-
30.	0.14	0.07	-	-	-	-	-
40.	0.21	0.14	0.07	-	-	-	-
50.	0.28	0.21	0.14	0.07	-	-	-
60.	0.35	0.28	0.21	0.14	0.07	-	-
70.	0.42	0.35	0.28	0.21	0.14	0.07	-
80.	0.49	0.42	0.35	0.28	0.21	0.14	0.07
90.	0.56	0.49	0.42	0.35	0.28	0.21	0.14

ADT LEVEL 10000. POLE OFFSET 25. FEET

POLE DENSITY BEFORE IMPROVEMENT (POLES/MILE)	POLE DENSITY AFTER IMPROVEMENT (POLES/MILE)						
	10.	20.	30.	40.	50.	60.	70.
20.	0.05	-	-	-	-	-	-
30.	0.10	0.05	-	-	-	-	-
40.	0.15	0.10	0.05	-	-	-	-
50.	0.21	0.15	0.10	0.05	-	-	-
60.	0.26	0.21	0.15	0.10	0.05	-	-
70.	0.31	0.26	0.21	0.15	0.10	0.05	-
80.	0.36	0.31	0.26	0.21	0.15	0.10	0.05
90.	0.41	0.36	0.31	0.26	0.21	0.15	0.10

Table 30. Expected number of utility pole accidents reduced due to decreasing pole density (Continued).

ADT LEVEL 15000. POLE OFFSET 3. FEET

POLE DENSITY BEFORE IMPROVEMENT (POLES/MILE)	POLE DENSITY AFTER IMPROVEMENT (POLES/MILE)						
	10.	20.	30.	40.	50.	60.	70.
20.	0.18	-	-	-	-	-	-
30.	0.37	0.18	-	-	-	-	-
40.	0.55	0.37	0.18	-	-	-	-
50.	0.73	0.55	0.37	0.18	-	-	-
60.	0.92	0.73	0.55	0.37	0.18	-	-
70.	1.10	0.92	0.73	0.55	0.37	0.18	-
80.	1.28	1.10	0.92	0.73	0.55	0.37	0.18
90.	1.47	1.28	1.10	0.92	0.73	0.55	0.37

ADT LEVEL 15000. POLE OFFSET 7. FEET

POLE DENSITY BEFORE IMPROVEMENT (POLES/MILE)	POLE DENSITY AFTER IMPROVEMENT (POLES/MILE)						
	10.	20.	30.	40.	50.	60.	70.
20.	0.11	-	-	-	-	-	-
30.	0.22	0.11	-	-	-	-	-
40.	0.33	0.22	0.11	-	-	-	-
50.	0.44	0.33	0.22	0.11	-	-	-
60.	0.55	0.44	0.33	0.22	0.11	-	-
70.	0.66	0.55	0.44	0.33	0.22	0.11	-
80.	0.77	0.66	0.55	0.44	0.33	0.22	0.11
90.	0.88	0.77	0.66	0.55	0.44	0.33	0.22

ADT LEVEL 15000. POLE OFFSET 15. FEET

POLE DENSITY BEFORE IMPROVEMENT (POLES/MILE)	POLE DENSITY AFTER IMPROVEMENT (POLES/MILE)						
	10.	20.	30.	40.	50.	60.	70.
20.	0.07	-	-	-	-	-	-
30.	0.14	0.07	-	-	-	-	-
40.	0.21	0.14	0.07	-	-	-	-
50.	0.28	0.21	0.14	0.07	-	-	-
60.	0.35	0.28	0.21	0.14	0.07	-	-
70.	0.42	0.35	0.28	0.21	0.14	0.07	-
80.	0.49	0.42	0.35	0.28	0.21	0.14	0.07
90.	0.56	0.49	0.42	0.35	0.28	0.21	0.14

ADT LEVEL 15000. POLE OFFSET 25. FEET

POLE DENSITY BEFORE IMPROVEMENT (POLES/MILE)	POLE DENSITY AFTER IMPROVEMENT (POLES/MILE)						
	10.	20.	30.	40.	50.	60.	70.
20.	0.05	-	-	-	-	-	-
30.	0.10	0.05	-	-	-	-	-
40.	0.15	0.10	0.05	-	-	-	-
50.	0.21	0.15	0.10	0.05	-	-	-
60.	0.26	0.21	0.15	0.10	0.05	-	-
70.	0.31	0.26	0.21	0.15	0.10	0.05	-
80.	0.36	0.31	0.26	0.21	0.15	0.10	0.05
90.	0.41	0.36	0.31	0.26	0.21	0.15	0.10

Table 30. Expected number of utility pole accidents reduced due to decreasing pole density (Continued).

ADT LEVEL 25000. POLE OFFSET 3. FEET

POLE DENSITY BEFORE IMPROVEMENT (POLES/MILE)	POLE DENSITY AFTER IMPROVEMENT (POLES/MILE) 10.	20.	30.	40.	50.	60.	70.
20.	0.18	-	-	-	-	-	-
30.	0.37	0.18	-	-	-	-	-
40.	0.55	0.37	0.18	-	-	-	-
50.	0.73	0.55	0.37	0.18	-	-	-
60.	0.92	0.73	0.55	0.37	0.18	-	-
70.	1.10	0.92	0.73	0.55	0.37	0.18	-
80.	1.28	1.10	0.92	0.73	0.55	0.37	0.18
90.	1.47	1.28	1.10	0.92	0.73	0.55	0.37

ADT LEVEL 25000. POLE OFFSET 15. FEET

POLE DENSITY BEFORE IMPROVEMENT (POLES/MILE)	POLE DENSITY AFTER IMPROVEMENT (POLES/MILE) 10.	20.	30.	40.	50.	60.	70.
20.	0.07	-	-	-	-	-	-
30.	0.14	0.07	-	-	-	-	-
40.	0.21	0.14	0.07	-	-	-	-
50.	0.28	0.21	0.14	0.07	-	-	-
60.	0.35	0.28	0.21	0.14	0.07	-	-
70.	0.42	0.35	0.28	0.21	0.14	0.07	-
80.	0.49	0.42	0.35	0.28	0.21	0.14	0.07
90.	0.56	0.49	0.42	0.35	0.28	0.21	0.14

ADT LEVEL 25000. POLE OFFSET 7. FEET

POLE DENSITY BEFORE IMPROVEMENT (POLES/MILE)	POLE DENSITY AFTER IMPROVEMENT (POLES/MILE) 10.	20.	30.	40.	50.	60.	70.
20.	0.11	-	-	-	-	-	-
30.	0.22	0.11	-	-	-	-	-
40.	0.33	0.22	0.11	-	-	-	-
50.	0.44	0.33	0.22	0.11	-	-	-
60.	0.55	0.44	0.33	0.22	0.11	-	-
70.	0.66	0.55	0.44	0.33	0.22	0.11	-
80.	0.77	0.66	0.55	0.44	0.33	0.22	0.11
90.	0.88	0.77	0.66	0.55	0.44	0.33	0.22

ADT LEVEL 25000. POLE OFFSET 25. FEET

POLE DENSITY BEFORE IMPROVEMENT (POLES/MILE)	POLE DENSITY AFTER IMPROVEMENT (POLES/MILE) 10.	20.	30.	40.	50.	60.	70.
20.	0.05	-	-	-	-	-	-
30.	0.10	0.05	-	-	-	-	-
40.	0.15	0.10	0.05	-	-	-	-
50.	0.21	0.15	0.10	0.05	-	-	-
60.	0.26	0.21	0.15	0.10	0.05	-	-
70.	0.31	0.26	0.21	0.15	0.10	0.05	-
80.	0.36	0.31	0.26	0.21	0.15	0.10	0.05
90.	0.41	0.36	0.31	0.26	0.21	0.15	0.10

Table 30. Expected number of utility pole accidents reduced due to decreasing pole density (Continued).

ADT LEVEL 40000. POLE OFFSET 3. FEET

POLE DENSITY BEFORE IMPROVEMENT (POLES/MILE)	POLE DENSITY AFTER IMPROVEMENT (POLES/MILE) 10.	20.	30.	40.	50.	60.	70.
20.	0.18	-	-	-	-	-	-
30.	0.37	0.18	-	-	-	-	-
40.	0.55	0.37	0.18	-	-	-	-
50.	0.73	0.55	0.37	0.18	-	-	-
60.	0.92	0.73	0.55	0.37	0.18	-	-
70.	1.10	0.92	0.73	0.55	0.37	0.18	-
80.	1.28	1.10	0.92	0.73	0.55	0.37	0.18
90.	1.47	1.28	1.10	0.92	0.73	0.55	0.37

ADT LEVEL 40000. POLE OFFSET 15. FEET

POLE DENSITY BEFORE IMPROVEMENT (POLES/MILE)	POLE DENSITY AFTER IMPROVEMENT (POLES/MILE) 10.	20.	30.	40.	50.	60.	70.
20.	0.07	-	-	-	-	-	-
30.	0.14	0.07	-	-	-	-	-
40.	0.21	0.14	0.07	-	-	-	-
50.	0.28	0.21	0.14	0.07	-	-	-
60.	0.35	0.28	0.21	0.14	0.07	-	-
70.	0.42	0.35	0.28	0.21	0.14	0.07	-
80.	0.49	0.42	0.35	0.28	0.21	0.14	0.07
90.	0.56	0.49	0.42	0.35	0.28	0.21	0.14

ADT LEVEL 40000. POLE OFFSET 7. FEET

POLE DENSITY BEFORE IMPROVEMENT (POLES/MILE)	POLE DENSITY AFTER IMPROVEMENT (POLES/MILE) 10.	20.	30.	40.	50.	60.	70.
20.	0.11	-	-	-	-	-	-
30.	0.22	0.11	-	-	-	-	-
40.	0.33	0.22	0.11	-	-	-	-
50.	0.44	0.33	0.22	0.11	-	-	-
60.	0.55	0.44	0.33	0.22	0.11	-	-
70.	0.66	0.55	0.44	0.33	0.22	0.11	-
80.	0.77	0.66	0.55	0.44	0.33	0.22	0.11
90.	0.88	0.77	0.66	0.55	0.44	0.33	0.22

ADT LEVEL 40000. POLE OFFSET 25. FEET

POLE DENSITY BEFORE IMPROVEMENT (POLES/MILE)	POLE DENSITY AFTER IMPROVEMENT (POLES/MILE) 10.	20.	30.	40.	50.	60.	70.
20.	0.05	-	-	-	-	-	-
30.	0.10	0.05	-	-	-	-	-
40.	0.15	0.10	0.05	-	-	-	-
50.	0.21	0.15	0.10	0.05	-	-	-
60.	0.26	0.21	0.15	0.10	0.05	-	-
70.	0.31	0.26	0.21	0.15	0.10	0.05	-
80.	0.36	0.31	0.26	0.21	0.15	0.10	0.05
90.	0.41	0.36	0.31	0.26	0.21	0.15	0.10

Table 30. Expected number of utility pole accidents reduced due to decreasing pole density (Continued).

ADT LEVEL 60000. POLE OFFSET 3. FEET

POLE DENSITY BEFORE IMPROVEMENT (POLES/MILE)	POLE DENSITY AFTER IMPROVEMENT (POLES/MILE)						
	10.	20.	30.	40.	50.	60.	70.
20.	0.18	-	-	-	-	-	-
30.	0.37	0.18	-	-	-	-	-
40.	0.55	0.37	0.18	-	-	-	-
50.	0.73	0.55	0.37	0.18	-	-	-
60.	0.92	0.73	0.55	0.37	0.18	-	-
70.	1.10	0.92	0.73	0.55	0.37	0.18	-
80.	1.28	1.10	0.92	0.73	0.55	0.37	0.18
90.	1.47	1.28	1.10	0.92	0.73	0.55	0.37

ADT LEVEL 60000. POLE OFFSET 15. FEET

POLE DENSITY BEFORE IMPROVEMENT (POLES/MILE)	POLE DENSITY AFTER IMPROVEMENT (POLES/MILE)						
	10.	20.	30.	40.	50.	60.	70.
20.	0.07	-	-	-	-	-	-
30.	0.14	0.07	-	-	-	-	-
40.	0.21	0.14	0.07	-	-	-	-
50.	0.28	0.21	0.14	0.07	-	-	-
60.	0.35	0.28	0.21	0.14	0.07	-	-
70.	0.42	0.35	0.28	0.21	0.14	0.07	-
80.	0.49	0.42	0.35	0.28	0.21	0.14	0.07
90.	0.56	0.49	0.42	0.35	0.28	0.21	0.14

ADT LEVEL 60000. POLE OFFSET 7. FEET

POLE DENSITY BEFORE IMPROVEMENT (POLES/MILE)	POLE DENSITY AFTER IMPROVEMENT (POLES/MILE)						
	10.	20.	30.	40.	50.	60.	70.
20.	0.11	-	-	-	-	-	-
30.	0.22	0.11	-	-	-	-	-
40.	0.33	0.22	0.11	-	-	-	-
50.	0.44	0.33	0.22	0.11	-	-	-
60.	0.55	0.44	0.33	0.22	0.11	-	-
70.	0.66	0.55	0.44	0.33	0.22	0.11	-
80.	0.77	0.66	0.55	0.44	0.33	0.22	0.11
90.	0.88	0.77	0.66	0.55	0.44	0.33	0.22

ADT LEVEL 60000. POLE OFFSET 25. FEET

POLE DENSITY BEFORE IMPROVEMENT (POLES/MILE)	POLE DENSITY AFTER IMPROVEMENT (POLES/MILE)						
	10.	20.	30.	40.	50.	60.	70.
20.	0.05	-	-	-	-	-	-
30.	0.10	0.05	-	-	-	-	-
40.	0.15	0.10	0.05	-	-	-	-
50.	0.21	0.15	0.10	0.05	-	-	-
60.	0.26	0.21	0.15	0.10	0.05	-	-
70.	0.31	0.26	0.21	0.15	0.10	0.05	-
80.	0.36	0.31	0.26	0.21	0.15	0.10	0.05
90.	0.41	0.36	0.31	0.26	0.21	0.15	0.10

APPENDIX D - PROJECTION OF ROADWAY AND ACCIDENT DATA

Future changes in the driver-vehicle-roadway system may affect utility pole accident experience as well as countermeasure effectiveness and cost-effectiveness. Changes in vehicle mix and volumes, vehicle fleet size and weight, occupant restraint systems, vehicle crashworthiness, and driver population are among the variables that could individually and in combination impact countermeasure cost-effectiveness and selection. Therefore, a cost-effectiveness analysis of long-term projects should at least consider the possible effects of future traffic, vehicle, and roadway conditions.

For example, consider a roadway section that has averaged 10 utility pole accidents per year for the past 3 years, and 40 percent of the accidents have involved personal injury. If conditions remain the same at the site, it may be relatively accurate to assume similar frequencies and severities for future utility pole accidents. However, a more likely scenario is that traffic volume will increase each year and smaller and lighter vehicles will occupy a greater proportion of the traffic mix. If these changes occur, utility pole accident frequency and severity would be expected to change as well as the relative effectiveness of various corrective treatments.

Although estimating future roadway and traffic conditions is quite difficult, the assumption that present traffic and vehicle conditions will remain constant will result in inaccuracies in estimating the long-term cost-effectiveness of utility pole accident countermeasures. Therefore, driver-vehicle-roadway system variables were identified which are expected to change over the next 25 years and have an effect on utility pole accident experience. A procedure was developed to predict the effect of these variables on utility pole accidents over the next 25 years.

Selection of Variables

A literature review was conducted to identify factors that could change the impact on utility pole accident experience over the next 25 years. These factors were categorized as follows:

- Utility pole-related features and countermeasures
- Physical roadway/roadside features
- Vehicle factors
- Traffic factors
- Driver factors

The first two categories (utility pole features and countermeasures, and roadway/roadside features) consist primarily of the direct and indirect countermeasures being evaluated in this research. These categories will have a definite long-range effect on utility pole accident experience and were therefore analyzed explicitly in the cost-effectiveness evaluation and not in the context of 25-year data projections.

The remaining categories (vehicle, traffic, and driver features) will change over time in response to a variety of social, legal, and economic conditions.

To summarize the findings relative to data projections, there are many transportation system characteristics that may affect the frequency, rate, or severity of utility pole accidents. However, only a few could be quantified for 25-year projections. The literature strongly suggested that increased usage of seat belts and air bags would result in reductions in fatalities and serious injury accidents but the downsizing of passenger cars will increase the probability of driver injury. Changes in recreational vehicle design, truck weight and size limits, and truck volumes are expected to have only a minor impact on utility pole accidents. Future changes in traffic volume were expected to have a definite impact on the frequency of utility pole accidents. The effects of many other vehicle, driver, and traffic characteristics were assessed and determined to have either negligible or unquantifiable effects on utility pole accident experience.

The following factors were selected for use in predicting future impacts of utility pole accident countermeasures:

1. Seat belt and air bag use
2. Passenger car downsizing
3. Traffic volumes

Application of Data Projections

To account for the possible changes caused by seat belts and air bag use, and passenger car downsizing, information from the literature was used to develop scenarios and associated adjustment factors. Information in studies by Smith et al. [1], were used in adjusting the severity of utility pole accidents for each of the four general scenarios for future lap belt and air bag use, as illustrated in figure 32.

For example, if average vehicle weights continue to decrease over the next 25 years with no increase in seat belt or air bag use, the percent of injury and fatal utility pole accidents is expected to increase. With the addition of air bags and 60 percent lap belt use, the ratio of serious injury and fatal accidents is expected to be reduced by about 50 percent in the next 25 years.

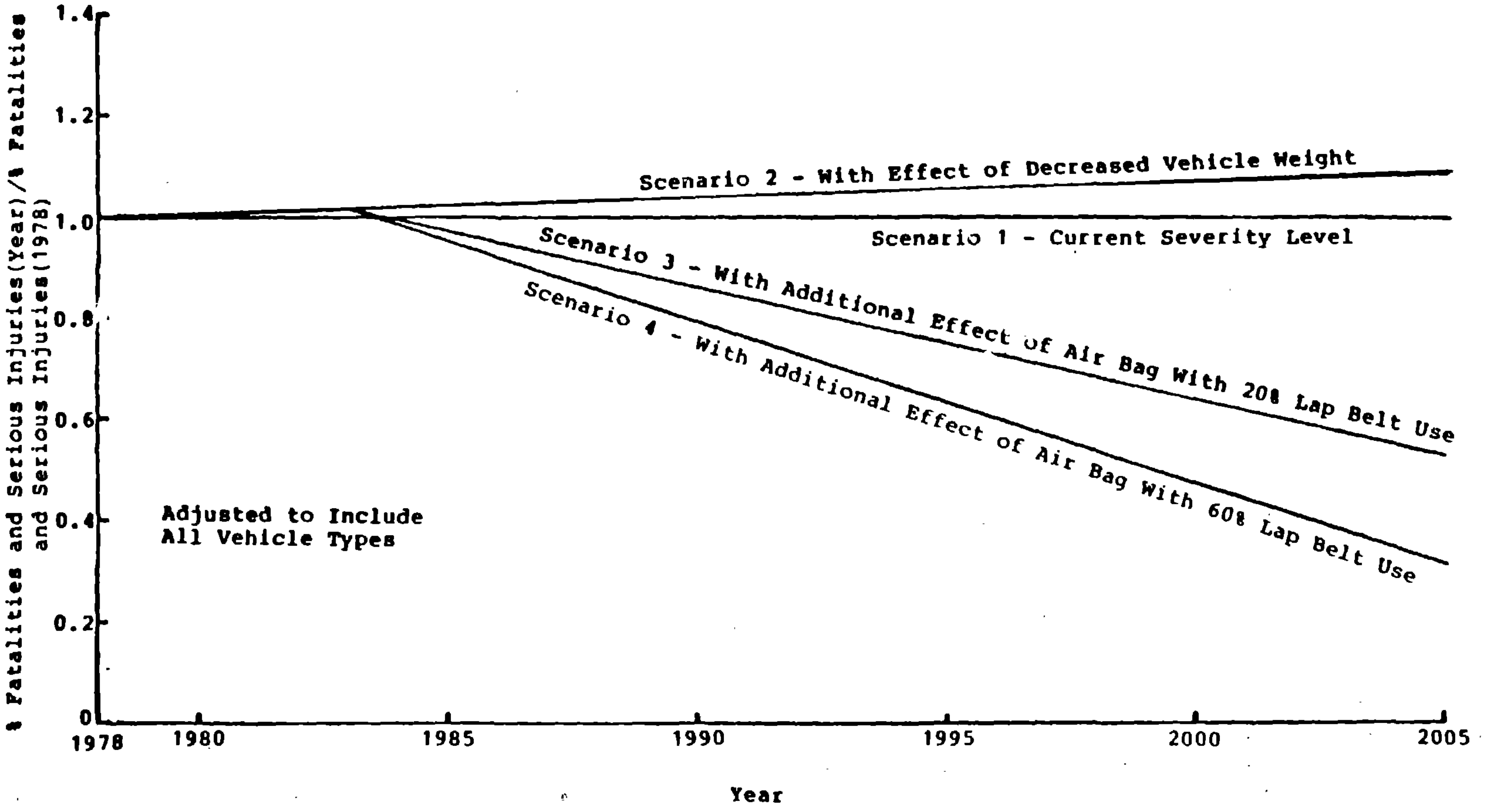

Figure 32. Scenarios of future accident severity on two-lane highways.

Source: Reference 1]

In terms of the effect of vehicle downsizing on accident severity, the study by Smith assumes an 11 percent increase in fatal and serious injury accident percentages due to vehicle downsizing from 1978 to 1995. However, studies by Strombotne and Griffin [2,3,4] support an 80 percent increase in fatal and serious injury percentages in utility pole passenger car accidents due to a projected drop in average new car weight of 3,800 pounds (curb weight) in 1975 to 2,600 pounds in 1995. The computer program allows for the user to select one of the two assumptions that is believed to be most appropriate.

Changes in future traffic volumes are expected to have an effect on the frequency of utility pole accidents. As traffic volume increases, the number of utility pole accidents is also expected to increase. In fact, the expected change in utility pole accidents caused by a change in traffic volume can be computed from the predictive model developed earlier for known levels of accident frequency and pole offset and density. Relationships between utility pole accidents and traffic volume are given in figure 33. for various pole offsets and a density of 50 poles per mile (31 poles/km), based on the predictive model [6].

The assumed changes in traffic volume (i.e., 5 percent per year, etc.) can either be inputed by the user for any given roadway section, or the model will select a value based on projections in "National Transportation Policies Through the Year 2000" [5]. These projections are given separately for various functional roadway classes based on a low growth, medium growth, or high growth assumptions.

The possible future effects of traffic volume, vehicle downsizing, and occupant restraint systems on utility pole accidents were incorporated in the cost-effectiveness computer program. The user of the program simply inputs his assumptions, and the expected effects of those assumptions are used to adjust the future utility pole accident experience for any proposed accident countermeasure. The manual cost-effectiveness procedure allows for considering changes in traffic volume but assumes no change in occupant restraint use or vehicle sizes in the traffic stream.

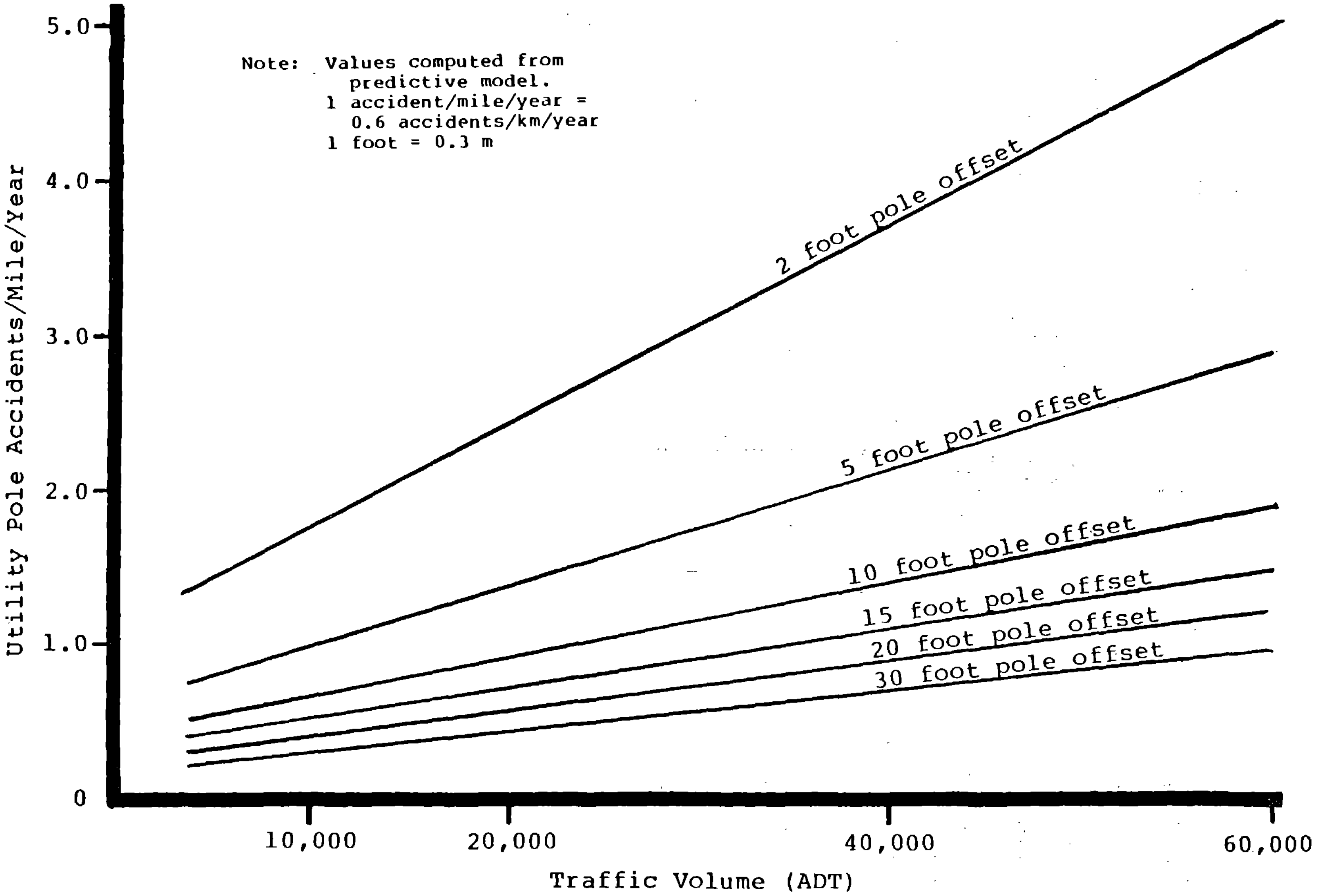

Figure 33. Relationship between traffic volume and utility pole accidents for pole densities of 50 poles/mile (31 poles/km).

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2. Strambotne, R.L. and Luchter, S., "Projections of Changes in Technology and Characteristics of Vehicles to Improve Fuel Economy," presented at TRB Annual Meeting, January 12-16, 1981.

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4. Griffin, L.I., "Probability of Overturn in Single Vehicle Accidents as a Function of Road Type and Passenger Car Curb Weight," Texas A&M University, November 1981.

5. "National Transportation: Trends and Choices (to the Year 2,000)," USDOT, Washington, D.C., 1977.

6. Zegeer, C.V., and Parker, M.R., "Cost-Effectiveness of Countermeasures for Utility Pole Accidents,"FHWA report, January 1983.

APPENDIX E - SAMPLE DATA FORMS

COST-EFFECTIVENESS ANALYSIS PROCEDURE FOR UTILITY POLE ACCIDENTS

FORM A: SITE DESCRIPTION

Road Name or Route Identification: ____________________

Beginning Milepoint: ________ Ending: ________ Length: ________ (Miles)

Area Type (Urban or Rural) ____________ Curb (Yes or No) ________

Right-of-Way Width: ____________ Shoulder Width: ____________ Feet

Current Daily Traffic Volume (ADT_C): ________ Speed Limit: ________ mph.

Expected Future Change in ADT = ___ percent/yr. or ___ percent in ___ yrs.

Utility Pole Location (one side or two): ____________

	No. of Poles	Pole Spacing	Poles/Mile	Avg. Pole Offset
Side 1:	________	________ ft.	________	________ ft.
Side 2:	________	________ ft.	________	________ ft.
Total:	________		________	________ ft.

Type of Utility Poles and Lines:

Side 1	Side 2 (if applicable)	
_____	_____	Wood telephone poles
_____	_____	Wood power poles carrying <69 KV lines
_____	_____	Non-wood poles
_____	_____	Heavy wood distribution and transmission poles
_____	_____	Steel transmission poles

Utility Pole Accident Data: ☐ Available ☐ Not Available

Utility Pole Accidents = ________ (total) for _____ years.

Utility Pole Accidents/Mile/Year (A_C) $= \dfrac{\text{No. of Utility Pole Accidents}}{(\text{Sec. Length}) \times (\text{Yrs. of Data})}$

A_C = ______ Utility Pole Accidents per mile per year

Percent injury & fatal Utility Pole Accidents = ______ %

Total Injuries: ____________ Total Fatalities: ____________

Coverage of other heavy fixed objects within 30 feet of roadway. Refer to Figures 10 to 15 to determine coverage factor (C_F) to use (check one):

____ 10% Roadside Coverage (See Figure 10)
____ 20% Roadside Coverage (See Figure 11)
____ 30% Roadside Coverage (See Figure 12)
____ 40% Roadside Coverage (See Figure 13)
____ 60% Roadside Coverage (See Figure 14)
____ 80% Roadside Coverage (See Figure 15)

COST-EFFECTIVENESS ANALYSIS PROCEDURE FOR UTILITY POLE ACCIDENTS

FORM B: COUNTERMEASURE DESCRIPTION

(Complete Form B for Each Countermeasure)

Countermeasure Number ____of____

Countermeasure to be Evaluated (Check One):

_____ Placement of Utility Lines Underground (Check One)

- _____ Telephone lines
- _____ Electric distribution lines <69 KV, direct bury, one phase
- _____ Electric distribution lines <69 KV, direct bury, three phase
- _____ Electric distribution lines <69 KV, conduit
- _____ Electric transmission lines >69 KV
- _____ Other:________________________________

_____ Pole Relocation from ____ feet to ____ feet from the edge of the pavement

_____ Increase Pole Spacing from____ to ____ feet. Thus the total number of poles on the section will be ___________ which translates to___________ poles per mile of roadway section.

_____ Pole Relocation from _____ feet to _____ feet from the edge of the roadway and Increase Pole Spacing to _____ feet which translates to ______ poles per mile of roadway section.

_____ Add Breakaway Pole Feature to _____ percent of poles. Expected reduction in injury and fatal accidents = ______%

_____ Multiple Pole Use (for a section with utility poles on both sides of the roadway) by removing utility lines from the line of poles closest to the roadway. The average offset of the remaining line of utility pole is ____feet from the edge of the roadway. The number of poles on the section would be ____ translating to ____poles per mile of section.

Expected change in annual maintenance cost (total section):

- _____ No change
- _____ Increase of $______ per year
- _____ Decrease of $______ per year
- _____ Unknown (assume $0 change if unknown)

Expected initial project costs (Specify):

$___________ Per Mile:____

$___________ Per Pole:____

$___________ Total:____

Expected countermeasure service life = _____ years (assume 20 years if unknown)

Interest rate = _______ percent per year (assume 12 percent if unknown)

COST-EFFECTIVENESS ANALYSIS PROCEDURE FOR UTILITY POLE ACCIDENTS

FORM C: WORK FORM

(Complete Form C for Each Countermeasure: See Coding Instructions)

STEP 1 - Complete the Site Inventory Form (Form A).

STEP 2 - Complete the Countermeasure Description Form (Form B). One Countermeasure Description Form should be completed for each countermeasure.

Countermeasure No.:____________

Countermeasure Description: ____________________________________

STEP 3 - Compute Average Traffic Volume over the Project Life (ADT_A)

Current ADT = _______ = ADT_C

- Method 3-A - Annual Growth Rate (g)

Annual Traffic Growth Rate (g) = ____ percent

Adjustment Factor = _______ = F_A (From Table 11)

$ADT_A = (ADT_C) \times F_A =$ _______ x _______ = _________

- Method 3-B - Overall Growth Rate (G)

Overall Growth Rate (G) = ___ percent

$ADT_A = ADT_C \frac{(2 + G/100)}{2} = \underline{\qquad} \frac{(2 + \underline{\quad}/100)}{2} = \underline{\qquad}$

STEP 4 - Determine Utility Pole Accidents Without Treatment (A_B)

- Method 4-A - Accident Predictive Model - Nomograph

ADT_A = __________ (Step 3)

Existing Pole Density = ____________ poles/mile (Form A)

Existing Pole Offset = ____________ feet (Form A)

A_B = _____________ Accidents per mile per year (Nomograph, Figure 8)

Note: If Method 4-A is used, $A_2 = A_B$.

COST-EFFECTIVENESS ANALYSIS PROCEDURE FOR UTILITY POLE ACCIDENTS

FORM C: WORK FORM

(Complete Form C for Each Countermeasure: See Coding Instructions)

- Method 4-B - Existing Accident Data

A_C = ______ accidents per mile per year based on existing accident experience (Form A)

Adjustment Factor to Convert Utility Pole Accident Experience From A_C to A_B

A_1 (From Nomograph, Figure 8) = ____________

ADT_C = ___________ (Form A)
Existing Pole Density = _______ poles/mile (Form A)
Existing Pole Offset = _______ feet (Form A)

A_2 (From Nomograph, Figure 8) = ____________

ADT_A = ___________ (Step 3)
Existing Pole Density = ___________ poles/mile (Form A)
Existing Pole Offset = ___________ feet (Form A)

$A_B = (A_C) \times (A_2/A_1)$ = ___ x (___/___) = ____ Accidents per mile per year

STEP 5 - Determine the Accident Reduction Factor (R_A) for utility pole accidents

A_F (from Nomograph, Figure 8) = ____________ Accidents per mile per year

ADT_A = ___________ (Step 3)
Proposed Pole Density = ___________ poles/mile (Form B)
Proposed Pole Offset = ___________ feet (Form B)

A_2 = __________ Accidents per mile per year (Step 4)

$R_A = \frac{A_2 - A_F}{A_2}$ = ______ - ______ = ________

R_A = _________ % Reduction in Utility Pole Accident Frequency

For the Breakaway Pole Countermeasure, Skip Steps 6 and 7, go to Step 8.

STEP 6 - Select the Roadside Adjustment Factor (H_R)

Skip for the Breakaway Pole Countermeasure

Coverage Factor (C_F) = ______________ (Form A)

H_R = _______ (0 to 1.0) from Tables 3, 4, 5 or 6.

COST-EFFECTIVENESS ANALYSIS PROCEDURE FOR UTILITY POLE ACCIDENTS

FORM C: WORK FORM

(Complete Form C for Each Countermeasure: See Coding Instructions)

STEP 7 - Compute the Number of Accidents Reduced (ΔA)

$\Delta A = (A_B) \times (R_A) \times (H_R) \times (L)$

ΔA = _____ x _____ x _____ x _____ = ______ Accidents per year

STEP 8 - Select the Average Cost Per Utility Pole Accident (C_A)

C_A = $7,007 based on 1981 NSC costs or $_____ based on ____

____ agency costs.

For the breakaway pole countermeasure, skip Step 9 and go to Step 10B

STEP 9 - Compute Accident Benefits Due to Reduced Accident Occurrences (B_A)

$B_A = (\Delta A) \times (C_A)$

B_A = ______ x $______ = $______ per year.

STEP 10 - Compute Accident Benefits Due to a Reduction in Accident Severity (B_S)

- Step 10-A - For all countermeasures except breakaway devices. Only for sections having speeds less than 45 mph.

  $B_S = (A_B) \times (1 - H_R) \times (R_A) \times (\Delta C_A) \times (L)$ [For ΔC_A, See Table 12]

  B_S = ______ x (1 - ______) x ______ x $______ x ______ = $______ per year

- Step 10-B - For the breakaway pole countermeasure only

  $B_S = (A_B) \times (\Delta C_A) \times (L)$ [For ΔC_A, See Table 13]

  B_S = ______ x $______ x ______ = $______ per year

STEP 11 - Compute Total Accident Benefits (B_T)

$B_T = BA + BS$

B_T = $______ + $______ = $______ per year

COST-EFFECTIVENESS ANALYSIS PROCEDURE FOR UTILITY POLE ACCIDENTS

FORM C: WORK FORM

(Complete Form C for Each Countermeasure: See Coding Instructions)

STEP 12 - Determine the Change in Maintenance Costs (C_M)

C_M = $______ per year. Use $0 if unknown

STEP 13 - Determine Countermeasure Installation Costs (C_I)

- Method 13-A - Cost Per Mile (C_L)

$C_I = (C_L) \times (CRF^i_n) \times (L)$

C_I = $______ x ______ x ______ = $______ per year

- Method 13-B - Cost Per Utility Pole (C_P)

$C_I = (C_P) \times (P_L) \times (CRF^i_n) \times (L)$

C_I = $______ x ______ x ______ x ______ = $______ per year

- Method 13-C - Total Project Cost (C_S)

$C_I = (C_S) \times (CRF^i_n)$ $______ x ______

C_I = $________ per year

STEP 14 - Calculate Total Project Cost (C_T)

$C_T = C_M + C_I$

C_T = $_____ + $_____ = $_____ per year.

STEP 15 - Calculate the Benefit-To-Cost Ratio (B/C)

$B/C = \frac{B_T}{C_T}$ = ______

COST-EFFECTIVENESS ANALYSIS PROCEDURE FOR UTILITY POLE ACCIDENTS

FORM D: COMPARISON OF COUNTERMEASURE

(Use This Form Only if 2 or More Countermeasures Are
Being Considered at the Same Location)

STEP 16 - Conduct Incremental Benefit-to-Cost Ratio Analysis (△B/△C).

List the Countermeasures in Order by Cost (C_T) from Lowest to Highest for those with a B/C ratio greater than 1.0 (or other acceptable minimum value).

Rank	Counter-measure Number	Total Annual Cost (C_T)	Total Annaul Benefits (B_T)	B/C Ratio	Compare	Incremental Change In Costs (△C)	Incremental Change In Benefits (△B)	Incremental Benefit/Cost Ratio △B/△C
Lowest Cost (C_T)								
2nd Lowest Cost								
3rd Lowest Cost								
4th Lowest Cost								
Highest Cost								

STEP 17 - Evaluate Available Funding and Other Agency Constraints

Select the remaining countermeasure with the highest incremental benefits to highest incremental costs.

Countermeasure No. and Description: ____________________

Countermeasure Cost: $____________ per year

Is funding available to complete project (Yes or No) ________

Do any other agency constraints prohibit implementation (Yes or No) ________

If yes, Describe: ____________________

If the project is unacceptable, select the countermeasure with the next highest incremental benefits to incremental costs until project is selected.

Countermeasure No. and Description: ____________________

Countermeasure Cost: $____________ per year

STEP 18 - Record Project Details

Selected Project: ____________________

Project Cost: $____________ per year

Total Project Cost: $____________ Change in Annual Maintenance Costs: $____________

Annual Accident Benefits: $____________

Utility Pole Accidents Reduced per year: ____________

B/C Ratio = ____________

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