Even industry does not suggest that casing pipes be eliminated all together. They acknowledge that there are certain instances when a casing pipe may provide optimum crossing protection. When evaluating a specific pipeline crossing location, all methods available to provide protection to both pipeline and highway should be considered.

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Determination of Cost-Effective Roadway Treatments for Utility Pole Accidents

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ABSTRACT

The purpose of this study was to determine the cost-effectiveness of alternative utility pole treatments. The study involved a large-scale data-collection and analysis effort to quantify benefits and costs associated with the following countermeasures: (a) placement of utility lines underground, (b) relocation of poles further from the roadway, (c) reducing the number of poles, (d) combinations of pole relocation and reducing pole density, and (e) use of breakaway poles. Expected accident benefits were computed for various countermeasures based on an in-depth analysis of accident and roadway data in four states. Countermeasure costs were obtained from telephone and electric utility companies around the country. Placing the utility lines underground and pole relocation were found to be cost effective for telephone and electric distribution lines for a variety of traffic and roadway conditions. Reducing pole density through multiple pole use was also cost effective in some instances, but increasing pole spacing was generally not cost effective. No countermeasures involving large transmission poles and lines were cost effective within the limits of the analysis. General guidelines were developed for selecting cost-effective countermeasures under various combinations of pole offset, traffic volumes, pole density (spacing), roadside conditions, and type of utility poles and lines.

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 accounted 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 NHTSA 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). Jones and Baum (3) analyzed more than 8,000 single-vehicle, fixed-object accidents in urban and suburban areas in 1980 and found that utility poles were 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.

Past research provides an adequate understanding of the utility pole accident problem and possible accident countermeasures. However, there is little information available concerning the cost-effectiveness of utility pole accident countermeasures. Because of the frequency and severity of utility pole accidents along U.S. roadways, there is an urgent need to identify cost-effective measures to reduce utility pole accident experience. This need for cost-effectiveness procedures exists at all levels of government responsible for highway safety.

The purpose of this paper is to describe a cost-effectiveness analysis procedure for the selection of alternative treatments to reduce the frequency, severity, or both, of utility pole accidents. This study involved the collection and analysis of roadway, roadside, and accident data to determine the accident experience associated with various roadside and utility pole features. The study resulted in a set of guidelines for the selection of cost-effective countermeasures for utility pole accidents on specific roadway sections based on different roadway characteristics, traffic volumes, and utility pole characteristics.

BACKGROUND

Several studies have addressed the effectiveness of such utility pole accident countermeasures as placing utility lines underground, increasing the lateral offset of poles, installing protective barriers, reducing the number of poles, using breakaway poles, or other countermeasures. Each countermeasure is discussed in the following paragraphs.

Most of the previous studies indicate that burying utility lines will reduce the overall severity of fixed-object accidents, based on the assumption that other, less-rigid objects will be hit instead (3-6). The net effect on the overall number of fixed-object accidents is unknown because it is highly dependent on site-specific roadside characteristics. Possible problems of placing utility lines underground include the high installation costs and the fact that many utility poles also carry attached streetlamps.

Increasing the lateral offset of poles is aimed at reducing the chance of a pole being struck. Mak and Mason (7) and Fox et al. (4) found an overrepresentation of pole accidents within 10 ft (3 m) of the roadway. The results of a 1978 study by Hunter et al. (5), however, suggest that moving poles away from the roadway will reduce fatal accidents, but it will not affect overall accident frequency because vehicles will hit other obstacles after pole relocation. In recognition of the possible increase in other fixed-object accidents due to pole relocation, Rinde (8) assumed no overall reduction in the frequency of fixed-object accidents, but indicated that a drop in accident severity will occur because the severity of striking a utility pole is generally greater than the severity of other fixed-object accidents.

Installing protective barriers involves the use of guardrail or impact-attenuating devices around or in front of the utility poles to lessen the severity of the accident. Studies by Griffin (9), Glennon (10), and Rinde (8) indicate that the installation of guardrail in front of utility poles may increase, instead of decrease, accident severity. Also, installation of guardrail in front of poles will likely increase the frequency of fixed-object accidents because the guardrail would be a larger obstacle than the pole itself and it must be placed closer to the roadway than the pole.

Reducing pole density is directed at decreasing the frequency of utility pole accidents. Treatments to reduce the numbers of poles include (a) multiple use of poles (i.e., poles that have telephone lines, electric lines, or luminaires), (b) placing poles on only one side of the street instead of both sides, and (c) increasing pole spacing. Jones and Baum (3) found that pole density was the variable most strongly correlated with utility pole accidents, although the precise impact of reducing poles (i.e., increasing pole spacings) was not quantified. One of the practical limitations of reducing the number of poles is that larger, more rigid poles may be needed to provide support for fewer poles or heavier utility lines. This can be costly, and the larger poles could have an adverse effect on the severity of utility pole accidents.

The use of breakaway poles is a countermeasure directed at reducing the severity of utility pole accidents and would be expected to have little or no effect on accident frequency. Several designs of breakaway poles have been developed and evaluated: (a) the steel SLIPBASE; (b) the retrofitting of poles by drilling holes or making sawcuts near the base; (c) the breakaway stub, where a section of pole near the base is designed to break away on impact; and (d) frangible bases, usually cast aluminum for metal poles that fracture on impact. Studies have concluded that breakaway poles can be effective in reducing the severity of utility pole accidents (11,12). Numerous problems, however, exist with the use of a breakaway pole (2,7,11,12). Also, the performance of a breakaway pole device has not yet been validated by in-service experience.

Other countermeasures also exist that could directly or indirectly reduce utility pole accident frequency or severity. For example, Jones and Baum (3) suggested that the use of occupant restraints (lap belts and shoulder harnesses) is probably the most cost-effective countermeasure for reducing the severity of utility pole accidents. Other indirect methods include (a) improving roadway delineation, (b) advance warning signs, (c) skid-resistant pavement overlays, (d) widening lanes and shoulders, (e) increasing highway lighting, and (f) improving roadway alignment through reconstruction.

These countermeasures may logically reduce utility pole accidents by reducing the possibility of a vehicle leaving the roadway, and thus reducing the probability of a utility pole accident. Although most of these treatments could have an effect on utility pole accidents in certain situations, they were not generally found to be justified based on utility pole accidents alone.

Based on a review of the literature, the countermeasures that appeared worthy of further consideration in this cost-effectiveness study were

1. Placing utility lines underground,
2. Increasing the lateral offset of poles,
3. Reducing the number of poles (multiple pole use, increased pole spacings, or using poles on only one side of the road),
4. Using combinations of increased lateral offset and reduced pole density, and
5. Using breakaway poles.

RESEARCH APPROACH

The research approach was structured to obtain detailed information regarding the installation and maintenance costs and the expected benefits (accident savings) of each countermeasure. Cost information was obtained from the literature and from information supplied by selected telephone and electric utility companies throughout the United States.

The estimation of accident benefits required a determination of the effectiveness of each proposed countermeasure on the frequency and severity of utility pole accidents. The literature was used to obtain information on the effect of breakaway utility poles and crash attenuators on utility pole accidents. A comparative analysis on a large data base was used for determining the effectiveness for the the other countermeasures.

A large sample was assembled of roadway, traffic, utility pole characteristics, and utility pole accident data for each of 1,534 roadway sections covering 2,519.3 total roadway miles (4030.9 km) collected from the states of Michigan, North Carolina, Washington, and Colorado. Accident data were obtained for 6 to 10 years at each roadway section, and more than 9,600 utility pole accidents were obtained for the test sections and used for analysis purposes. Data collection involved the use of agency files, photologs, police accident records, and some site visits.

Statistical analyses were conducted on the data by using comparative analyses and nonlinear regression models to predict utility pole accidents for various combinations of utility pole and roadway features. The results of the analyses were used to determine accident reduction factors resulting from various countermeasures and corresponding accident benefits for implementing each countermeasure at a variety of traffic and roadway conditions. Corresponding countermeasure costs were also found and used in the cost-effectiveness analysis.

COUNTERMEASURE EFFECTIVENESS

Utility Pole Accident Predictive Model

One of the objectives of the study was to develop a model to predict utility pole accident experience as a function of roadway and utility pole characteristics. The analysis of the data base indicated that the variables most highly related to accident experience included lateral pole offset from the edge of the roadway, utility pole spacing (density), and traffic volume. The best-fit regression model developed to predict utility pole accidents is

$$\text{Acc/Mi/Yr} = [9.84 \times 10^{-5}\,(\text{ADT}) + 3.54 \times 10^{-2}\,(\text{DENSITY}) \div (\text{OFFSET})^{0.6}] - 0.04 \tag{1}$$

where

Acc/Mi/Yr = number of predicted utility pole accidents per mile (1.6 km) per year,
ADT = annual average daily traffic volume,
DENSITY = number of utility poles per mile within 30 ft (10 m) of the roadway, and
OFFSET = average lateral offset of the utility poles (ft) from the roadway edge on the section.

A nomograph was developed from the model as part of the overall study; it is illustrated in a related article (13). Based on the traffic volume, pole density, and pole offset, the nomograph, or predictive equation, can be used to obtain the approximate frequency of utility pole accidents. Specific effects of pole offset and pole density on the frequency of utility pole accidents were quantified based on the analysis of covariance and the use of the predictive model and nomograph. Factors were also identified that were associated with the severity of utility pole accidents. The literature was also used to help quantify countermeasure effectiveness. Further details of this comprehensive analysis may be found in another source (14). The following paragraphs describe the accident benefits from utility pole countermeasures based on the analysis of the data. The effectiveness information of countermeasures on the frequency and severity of utility pole accidents is summarized in Table 1.

Roadside Adjustment Factor

Most roadside conditions have other fixed objects, curbs, or sideslopes, so the net reduction in roadside accidents due to utility pole countermeasures 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 instead may (a) have no collision at all (the vehicle may recover), (b) hit some other fixed object, or (c) 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. Glennon (10) developed a roadside hazard model for comparisons of roadside improvements in a previous NCHRP study. The model was later refined to more accurately predict general roadside hazards.

The roadside adjustment factor used for this study involves merely adjusting the expected utility pole accidents (based on the accident data analysis) for various types of roadsides. The model does not depend on encroachment rates in any way. The inputs into the roadside adjustment model include coverage of fixed objects along the road (0 to 100 percent), lateral offset of fixed objects, spacing and lateral offset of utility poles before and after implementation of the countermeasure, the distribution of lateral displacement of encroaching vehicles (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, and the assumed percentage of run-off-road accidents reported. Example roadside adjustment factors for placing poles underground, increasing lateral pole offsets, and reducing pole density through multiple pole use are given in Table 2.

To use the adjustment factor in this study, the percent coverage of fixed objects must be known for a given roadway section. The coverage factor used in this study is based on work by Graham and Harwood (14) in a study of clear recovery zones. This factor is based on the number and types of fixed objects within a specified distance along the roadway.

Because 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 that are most effective in reducing utility pole accidents (i.e., placing lines underground) will result in the greatest increase in accidents corresponding to other fixed objects, because encroaching vehicles will then hit other objects instead of utility poles.

COSTS OF UTILITY POLE COUNTERMEASURES

To evaluate the cost-effectiveness of the various

TABLE 1 Summary of Effectiveness for Various Utility Pole Countermeasures

Countermeasure	Effect on Utility Pole Accident Frequency	Effect on Utility Pole Accident Severity
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 49.3% to 29.0% (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.
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 49.3% to 29.0% in urban areas.
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 49.3% to 29.0% (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.
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 49.3% to 29.0% (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.
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 result of 0 to 60% reduction in injury and fatal accidents may be input by the user.

utility pole accident countermeasures, a range of project costs were formulated for each alternative utility pole treatment. A thorough search of the literature and discussions with utility companies were used to obtain cost factors relevant to this study. These cost factors were placed into the general categories of direct and indirect costs. Direct countermeasure costs include capital investment costs, maintenance and overhead costs, and right-of-way acquisition costs. Indirect costs include traffic delay and detour costs, utility company liability (insurance) costs, utility service interruption costs, and other societal costs.

Direct Costs

Countermeasure costs vary widely because of regional variations in construction and labor costs, differences in utility company policies and procedures, type and size of the utility line, degree of urbanization of the construction site, salvageability of utility poles, and many other factors. A discussion of the direct costs for a variety of countermeasures relative to utility pole accidents follows.

Place Utility Lines Underground

Placing utility lines underground is often a costly and labor-intensive countermeasure. It is a two-stage process involving pole removal and cable burial.

Eight telephone companies provided costs for placing their lines underground. Costs for replacing overhead lines with underground lines averaged $18,000 per mile in rural areas ($11,000/km) and $36,000 per mile in urban areas ($22,500/km). Costs for placing lines underground were also obtained from 21 large electric companies in 20 states. The costs varied widely from $20,000 to $1.7 million per mile ($12,500 to $1.1 million/km), depending on factors such as types of poles, lines, voltages, and construction methods. To simplify this analysis, costs from various telephone and electric companies are summarized by area type (urban or rural) within the following categories: (a) transmission lines, $\geq$ 69 Kv, conduit used; (b) distribution lines, < 69 Kv, conduit used; (c) distribution lines, < 69 Kv, direct burial, three-phase line; and (d) distribution lines, < 69 Kv, direct burial, one-phase line.

The average cost for placing large transmission lines underground was $1.2 million per mile ($0.75 million/km). For placing distribution lines in conduit underground, costs averaged about $430,000 per mile ($269,000/km) in rural areas and $650,000 per mile ($406,000/km) in urban areas. A summary of costs for placing lines underground is given in Table 3, as obtained from the electric and telephone companies.

Relocate Utility Poles Farther From Roadway

Costs for relocating utility poles were obtained from 10 telephone companies. The average relocation costs for telephone poles (excluding right-of-way

TABLE 2 Roadside Adjustment Factors for Placing Utility Lines Underground, Increasing Lateral Offsets, and Multiple Pole Use

Utility Lines Undergrounding

Pole Offset (Feet)	Rural Areas: Coverage of Fixed-Objects 10%	35%	60%	Urban Areas: Coverage of Fixed-Objects 10%	35%	60%
2	0.619	0.497	0.374	0.706	0.574	0.443
5	0.611	0.486	0.361	0.670	0.513	0.356
10	0.564	0.433	0.295	0.611	0.441	0.271
15	0.543	0.407	0.241	0.530	0.383	0.236
20	0.521	0.376	0.231	0.400	0.289	0.178
25	0.471	0.340	0.210			
30	0.400	0.289	0.178			

Increasing Lateral Pole Offset

Pole Offset (Feet) Before Improvement	After Improvement	Area Type (Urban or Rural)	Coverage of Fixed-Objects 10%	35%	60%
2	30	R	0.716	0.589	0.461
5	30	R	0.708	0.576	0.445
10	30	R	0.661	0.509	0.357
15	30	R	0.650	0.469	0.277
20	30	R	0.650	0.469	0.289
25	30	R	0.650	0.469	0.289
2	20	R	0.763	0.672	0.582
5	20	R	0.703	0.655	0.560
10	20	R	0.672	0.548	0.423
15	20	R	0.650	0.469	0.289
2	20	U	0.833	0.693	0.552
5	20	U	0.816	0.634	0.452
10	20	U	0.800	0.578	0.356
15	20	U	0.800	0.578	0.356
2	10	U	0.861	0.791	0.721
5	10	U	0.840	0.718	0.596

Multiple Pole Use

Pole Offset (Feet)	Rural Areas: Coverage of Fixed-Objects 10%	35%	60%	Urban Areas: Coverage of Fixed-Objects 10%	35%	60%
2	0.619	0.497	0.374	0.823	0.659	0.495
5	0.611	0.486	0.361	0.810	0.614	0.418
10	0.571	0.433	0.295	0.800	0.578	0.356
15	0.543	0.392	0.241	0.800	0.578	0.356
20	0.521	0.376	0.231			
25	0.471	0.340	0.210			
30	0.400	0.289	0.178			

Note: 1 foot = 0.3 m

costs) were $345 per pole in rural areas and $425 per pole in urban areas. Pole relocation costs were obtained from 31 electric companies. The costs for relocating poles from electric companies are given in four categories:

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

A summary of the average and ranges of pole relocation costs is given in Table 4, as reported by telephone and electric companies.

Reduce Pole Density

As previously mentioned, reducing pole density can involve three subcategories of countermeasures: (a) increased utility pole spacing, (b) the use of poles for multiple purposes, or (c) the use of one line of poles instead of two. Increasing the pole spacing for safety purposes would most likely require larger

TABLE 3 Summary of Costs for Placing Utility Lines Underground

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 ≥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).

poles because existing pole spacing is based on structural considerations. The cost for increased pole spacing can be approximated by the cost of pole relocation, as given in Table 4.

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

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 is basically similar to multiple pole use, and costs are assumed to be comparable to multiple pole use.

Conversion to Breakaway Poles

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 ranges from about $36 to $80. However, by including the costs of shortened pole life and pole replacement costs, the cost per pole was found to be about $1,000 per pole by Mak and Mason (7). The costs of a SLIPBASE are also about $1,000 per pole for small or medium-sized poles.

Indirect Costs

Indirect costs are not as easily defined or measured as direct costs. During construction indirect costs might be incurred by the motorist in the form of in-

TABLE 4 Summary of Costs for Relocating Utility Lines

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).

creased stops or delays, excess fuel consumption, increased travel time, or inconvenience, 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 for traffic detours during construction, and administrative and overhead costs.

The issue of indirect costs associated with utility pole accident countermeasures is quite complex. Such costs may change drastically from one site to another for the same type of countermeasure. Although it may be possible to quantify indirect costs for use in site-specific evaluations, the quantification of indirect costs was not included in this analysis.

COST-EFFECTIVENESS ANALYSIS

The benefit-cost (B/C) method was selected for analysis of individual projects because of its common use relative to other safety improvements, its ease of interpretation, and its ease of manual computation. In addition, a B/C ratio of 1.0 or greater is considered a justifiable project. The incremental B/C ratio method should be used to compare different project alternatives at a site or for selecting optimal projects at numerous sites. To use the B/C and incremental B/C economic analysis techniques, numerous inputs must be provided (see Table 5).

RESULTS OF COST-EFFECTIVENESS ANALYSIS

A cost-effectiveness analysis was conducted for each of the five countermeasures for a variety of traffic and roadway conditions. The results of the cost-effectiveness computations are highly sensitive to many different variables. Therefore, it was not possible to express the cost-effectiveness of a given countermeasure in general terms. For example, the utility pole accident experience resulting from any given countermeasure at a site is highly sensitive to traffic volume, pole offset, and pole density. The area type and type of utility poles and lines have a major impact on the cost of the countermeasure. The roadside characteristics (particularly the coverage factor of other fixed objects) are important in determining the net effect of the countermeasure on total roadside accidents.

To simplify the general cost-effectiveness analysis procedure for this study, an interest rate of 12 percent was assumed. Accident costs of $7,007 per utility pole accident and a $2,477 cost savings per accident for a utility pole accident converted into a run-off-road accident in urban areas was computed based on 1981 National Safety Council (NSC) costs and on the severity distribution of the 9,600 utility pole accidents collected for this study. Other assumptions include a 20-year project life, a $0 salvage value, and a negligible change in maintenance costs because of the countermeasure. These assumptions were based on information found in the literature and data provided by more than 40 utility companies.

Based on these assumptions, a cost-effectiveness analysis was conducted for each of the five potential countermeasures. Roadway situations were analyzed with

1. Traffic volumes between 1,000 and 60,000;
2. Pole offsets of 2 to 30 ft (0.6 to 9.0 m);
3. Pole densities of 10 to 90 poles per mile (6 to 54 poles/km);
4. Urban, urban fringe, and rural areas; and
5. A variety of roadside conditions (ranging from roadsides clear of other fixed objects to roadsides with a high coverage of fixed objects).

This analysis procedure is not applicable for freeway conditions or for sections with poles in the median. The following is a summary of the findings.

Place Utility Lines Underground

To compute the B/C ratio for placing utility lines

TABLE 5 Summary of Inputs Used in Cost-Effectiveness Analysis

Inputs	Values Used In This Analysis	Comments
Expected future traffic volume on the roadway section	1,000 to 20,000 in rural areas, 1,000 to 60,000 in urban areas	Based on projected growth in ADT's.
Expected utility pole accident experience	Values from the predictive model	Historical data should be used where possible. If not available use the predictive model or the nomograph.
Expected change in occupant restraint usage and vehicle sizes	No change	Various scenarios can be used as discussed in the Final Report [14].
Initial countermeasure cost	Average values in Tables 3 and 4	Costs should be site specific and should include both direct and indirect costs. Costs vary widely based on region of the country, area type, construction methods, etc.
Expected change in annual maintenance costs due to the countermeasure	$0	Costs should be site specific.
Accident reduction factor due to the countermeasure	Based on predictive model or nomograph	
Roadside adjustment factor	Values from Table 2	Use site specific values (see Final Report [14]).
Unit accident costs	$7,007 per utility pole accident and $2,477 for utility pole accidents converted to run-off-road accidents. Based on 1981 NSC accident costs.	Use NSC/NHTSA or individual states accident costs.
Service life of the countermeasure	20 Years	Generally ranges from 20 to 30 years
Salvage value associated with the countermeasure	$0	Can be positive, negative or zero, usually very small.
Interest rate of money	12 percent	Can have a considerable effect on cost-effectiveness analysis results. Use actual rate for agency.

underground in rural areas, benefits and costs were computed on an annual basis. Benefits used were the savings due to the reduction of accidents per mile per year. Costs were the initial construction costs annualized over a 20-year life. The roadside adjustment factor (H_R) was multiplied by the benefits to account for the possible increase in other run-off-road accidents after the utility poles were removed. Thus the computation of B/C ratio in rural areas is as follows:

$$B/C = [(A_B)(C_A)(H_R)(R_A)]/C_I\,(CRF) \qquad (2)$$

where

- B/C = benefit-cost ratio;
- A_B = utility pole accidents before improvement per mile per year, as determined from the predictive equation or nomograph;
- C_A = average cost of a utility pole accident ($7,007);
- R_A = percentage reduction in utility pole accidents expected because of the countermeasure; for placing utility lines underground, R_A is assumed to be 1.0, or 100 percent;
- H_R = roadside adjustment factor used to account for an increase in other types of run-off-road accidents because of placing utility lines underground (value between 0 and 1.0);
- C_I = initial construction cost for the project of placing lines underground (dollars per mile) (Table 3); and
- CRF = capital recovery factor for a 20-year service life and 12 percent compound interest rate (CRF = 0.13388).

The B/C ratio for placing utility lines underground in urban areas is computed for the net reduction in accidents and a decrease in severity of the additional run-off-road accidents as follows:

$$B/C = [(A_B)(C_A)(H_R)(R_A) + (1 - H_R)(A_B)(R_A)(\Delta C_A)]/C_I\,(CRF) \qquad (3)$$

where $(1 - H_R)$ is the percentage of utility pole accidents that will become other types of run-off-road accidents after completing the placement of lines underground, and ΔC_A is the change in accident cost for the increased run-off-road accidents in urban areas (assumed to be $2,477).

A summary of B/C ratios is given in Table 6 for placing telephone lines underground in urban areas for various combinations of pole offsets, roadside coverage of fixed objects, traffic volume, and pole density.

Based on the analysis, it was found that placing lines underground is not generally cost effective for transmission lines, electric lines requiring conduits, and three-phase electric lines because of the high costs associated with such improvements. However, placing telephone lines and small electric lines (one phase) underground is cost effective in many situations, particularly where the pole offset is within 5 ft (1.5 m), traffic volume is greater than 5,000, and the roadside is relatively clear of other fixed objects.

Increase Lateral Pole Offset

The B/C ratio for increasing lateral pole offset in rural areas is as follows:

$$B/C = [(A_B)(C_A)(R_A)H_R]/C_I\,(CRF) \qquad (4)$$

As with the placement of lines underground, additional benefits may be obtained from pole relocation

TABLE 6 Summary of B/C Ratios for Placing Telephone Lines Underground in Urban Areas for a Variety of Traffic and Roadway Conditions

Pole Offset (Feet)	ADT	Clear, Level Roadside			≤ 10% Fixed Object Coverage			≤ 35% Fixed Object Coverage			≤ 60% Fixed Object Coverage		
		Pole Density (Poles/Mile)			Pole Density (Poles/Mile)			Pole Density (Poles/Mile)			Pole Density (Poles/Mile)		
		30	50	70	30	50	70	30	50	70	30	50	70
2	1,000	1.05	1.73	2.41	0.85	1.40	1.95	0.76	1.26	1.73	0.67	1.11	1.54
	5,000	1.43	2.11	2.79	1.16	1.71	2.26	1.04	1.53	2.02	0.92	1.35	1.79
	10,000	1.90	2.58	3.26	1.54	2.09	2.64	1.38	1.87	2.36	1.22	1.65	2.09
	20,000	2.85	3.53	4.21	2.31	2.86	3.41	2.06	2.55	3.05	1.82	2.26	2.69
	40,000	4.73	5.41	6.09	3.83	4.38	4.93	3.43	3.92	4.41	3.03	3.46	3.90
	60,000	6.62	7.30	7.98	5.36	5.91	6.46	4.80	5.29	5.78	4.24	4.67	5.11
5	1,000	0.58	0.97	1.37	0.46	0.77	1.08	0.40	0.67	0.94	0.34	0.57	0.80
	5,000	0.80	1.19	1.58	0.63	0.94	1.25	0.55	0.82	1.09	0.47	0.70	0.92
	10,000	1.07	1.46	1.86	0.84	1.15	1.46	0.73	1.00	1.27	0.63	0.85	1.08
	20,000	1.62	2.01	2.40	1.27	1.58	1.89	1.11	1.38	1.65	0.94	1.17	1.40
	40,000	2.71	3.10	3.49	2.13	2.44	2.75	1.85	2.12	2.39	1.58	1.81	2.04
	60,000	3.79	4.19	4.58	2.99	3.29	3.60	2.60	2.87	3.14	2.21	2.44	2.67
10	1,000	0.36	0.62	0.88	0.27	0.47	0.66	0.23	0.40	0.56	0.19	0.33	0.47
	5,000	0.51	0.77	1.02	0.38	0.57	0.77	0.32	0.49	0.65	0.27	0.40	0.54
	10,000	0.69	0.95	1.20	0.51	0.71	0.90	0.44	0.60	0.77	0.36	0.50	0.64
	20,000	1.05	1.30	1.56	0.78	0.98	1.17	0.67	0.83	1.00	0.55	0.69	0.83
	40,000	1.76	2.02	2.28	1.32	1.51	1.71	1.13	1.29	1.46	0.93	1.07	1.21
	60,000	2.48	2.74	3.00	1.86	2.05	2.25	1.59	1.75	1.92	1.31	1.45	1.59
15	1,000	0.27	0.47	0.68	0.19	0.33	0.47	0.16	0.29	0.41	0.14	0.24	0.34
	5,000	0.38	0.59	0.79	0.27	0.41	0.55	0.23	0.35	0.47	0.19	0.30	0.40
	10,000	0.53	0.73	0.93	0.37	0.51	0.65	0.32	0.44	0.56	0.27	0.37	0.47
	20,000	0.81	1.01	1.21	0.56	0.70	0.84	0.48	0.61	0.73	0.41	0.51	0.61
	40,000	1.37	1.57	1.78	0.95	1.10	1.24	0.82	0.95	1.07	0.69	0.80	0.90
	60,000	1.93	2.14	2.34	1.35	1.49	1.63	1.16	1.28	1.41	0.98	1.08	1.18

Note: All values assume a cost of $36,000 per mile for undergrounding of telephone lines in urban areas.

1 foot = 0.3 m
1 pole/mile = 0.6 poles/km

in urban areas. Thus the equation for B/C ratio for pole relocation in urban areas is

$$B/C = [(A_B)(C_A)(R_A)(H_R) + (1 - H_R)(A_B)(R_A)(\Delta C_A)]/C_I\,(CRF) \quad (5)$$

where R_A is the percentage reduction in utility pole accidents expected from increasing pole offsets (for the cost-effectiveness analysis, R_A was computed from the predictive equation for various roadway situations), and C_I is the cost for relocating poles (values of C_I used for the cost-effectiveness analysis are given in Table 4).

Based on the analysis, increasing pole offsets to 10 to 20 ft (3 to 6 m) in urban areas or from 20 to 30 ft (6 to 9 m) in rural areas is cost effective in many situations for telephone poles and for small electric power poles, particularly where pole offsets are less than 5 ft (1.5 m), traffic volumes exceed 5,000, and the roadside is reasonably clear of other fixed objects. A summary of B/C ratios for relocating telephone poles and lines in rural areas is given in Table 7. Relocation of steel transmission poles is not cost effective within the limits of the analysis (because of high countermeasure costs), and relocation of heavy wood distribution poles and nonwood (metal and concrete) poles is cost effective only in a few instances.

Multiple Pole Use

Multiple pole use for this analysis was assumed to involve a roadway with a row of poles located on both sides of the road at similar pole offsets, in which one line of poles is removed and the lines are strung on the poles on the other side of the street. For purposes of this analysis, it is assumed that a row of telephone poles will be taken down and the lines strung on poles (probably larger electric distribution poles) on the other side of the roadway, as is common practice. The equation for computing the B/C ratio for this countermeasure in rural areas is as follows:

$$B/C = [(A_B)(R_A)(C_A)(H_R)]/C_I\,(CRF) \quad (6)$$

where R_A is the accident reduction factor from reducing pole density by 50 percent (removing half of the poles) [the value for R_A was computed based on the predictive equation (nomograph)], and C_I is the cost for removing one line of poles and installing the lines on existing poles on the other side of the road [for this analysis the costs assumed for this improvement are for removing telephone poles and attaching the lines to electric poles; the assumed costs for this countermeasure are $8,700 per mile ($5,400/km) for rural areas and $11,000 per mile ($6,900/km) for urban areas].

The equation used for computing B/C ratios in urban areas was the same as given for placing lines underground and pole relocation, except that A_R (accident reduction factor) was computed from the predictive equation assuming a 50 percent reduction in pole density (converting two lines of poles to one line of poles). The results indicate that multiple pole use is cost effective for several combinations of pole offset, pole density, and coverage of fixed objects (Table 8).

Increase Pole Spacing

For this analysis the cost-effectiveness of increased pole spacing was computed for a 20 percent reduction in the number of poles, which would result in a 20 percent increase in pole spacing. No adverse

TABLE 7 Summary of B/C Ratios for Relocating Telephone Poles and Lines in Rural Areas (35 percent coverage factor)

Pole Offset (Feet)			Pole Density (Poles Per Mile)		
Before Improvement	After Improvement	ADT	30	50	70
2	20	1,000	1.95	1.88	1.86
		5,000	2.61	2.28	2.14
		10,000	3.44	2.78	2.49
		20,000	5.09	3.77	3.20
2	30	1,000	1.83	1.77	1.74
		5,000	2.45	2.14	2.01
		10,000	3.23	2.61	2.34
		20,000	4.78	3.54	3.01
5	20	1,000	0.83	0.80	0.79
		5,000	1.11	0.97	0.91
		10,000	1.46	1.18	1.06
		20,000	2.16	1.60	1.36
5	30	1,000	0.85	0.82	0.81
		5,000	1.14	0.99	0.93
		10,000	1.50	1.21	1.08
		20,000	2.21	1.64	1.39
10	20	1,000	0.28	0.27	0.26
		5,000	0.37	0.32	0.30
		10,000	0.48	0.39	0.35
		20,000	0.72	0.53	0.45
10	30	1,000	0.36	0.35	0.34
		5,000	0.49	0.42	0.40
		10,000	0.64	0.52	0.46
		20,000	0.95	0.70	0.59

Note: Values assume a cost of $345 per pole.

1 foot = 0.3 m
1 pole/mile = 0.6 poles/km

TABLE 8 Summary of B/C Ratios for Multiple Pole Use

		Rural Areas				Urban Areas			
Pole Offsets (Feet)	Pole Density (Poles/ Mile)	Clear, Level Roadside 0% Fixed Object Coverage	Low Fixed Object Coverage ≤10%	Medium Fixed Object Cover-age (≤35%)	High Fixed Object Cover-age (≤60%)	Clear, Level Roadside 0% Fixed Object Coverage	Low Fixed Object Coverage ≤10%	Medium Fixed Object Cover-age (≤35%)	High Fixed Object Cover-age (≤60%)
2	30	2.11	1.31	1.05	0.79	1.67	1.48	1.30	1.12
	50	3.52	2.18	1.75	1.32	2.78	2.46	2.17	1.87
	70	4.92	3.05	2.45	1.84	3.89	3.45	3.04	2.62
5	30	1.22	0.74	0.59	0.44	0.96	0.84	0.72	0.60
	50	2.03	1.24	0.99	0.73	1.60	1.41	1.20	1.00
	70	2.84	1.74	1.38	1.03	2.25	1.97	1.69	1.40
10	30	0.80	0.46	0.35	0.24	0.64	0.55	0.46	0.37
	50	1.34	0.76	0.58	0.39	1.06	0.92	0.77	0.62
	70	1.87	1.07	0.81	0.55	1.48	1.29	1.08	0.87
15	30	0.63	0.34	0.25	0.15	0.50	0.43	0.36	0.29
	50	1.05	0.57	0.41	0.25	0.83	0.72	0.60	0.48
	70	1.47	0.80	0.58	0.35	1.16	1.01	0.85	0.68

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

effect on accident severity was assumed in the likelihood that a more rigid pole is used as a result of the increased pole spacings. The costs for this countermeasure were assumed to be similar to the cost of pole relocation. The equation for the B/C ratio was similar to those mentioned for pole relocation in urban and rural areas. The accident reduction factor was computed from the predictive equation based on a 20 percent reduction in pole density.

The results of this analysis indicate that increasing pole spacing by 20 percent is not cost effective under any situation within the range of the analysis. Even for traffic volumes of 60,000 with 2-ft (0.6-m) pole offsets and a roadside clear of other fixed objects, the B/C ratio was 0.58 in urban areas. In rural areas the highest B/C ratio for this countermeasure was 0.71.

Use of Breakaway Poles

Because efforts continue on the development and testing of various breakaway pole devices, the accident benefits assumed for the cost-effectiveness analysis were two hypothetical levels, as follows: (a) a 30 percent reduction in injury and fatal accidents, and (b) a 60 percent reduction in injury and fatal accidents. Although the average cost per utility pole accident is assumed to decrease because of the addition of a breakaway pole device, the frequency of accidents is assumed to be unchanged because of the breakaway poles. For this analysis, the breakaway poles were assumed to be installed on all utility poles within a roadway section.

The equation for computing the B/C ratio for the breakaway poles is as follows:

$$B/C = [(A_B)(\Delta A_C)]/[C_I(CRF)D] \quad (7)$$

where

- ΔA_C = change in average accident cost due to the breakaway devices,
- D = number of utility poles per mile on a section, and
- C_I = cost for each breakaway device, which is assumed to be $1,000 per pole based on cost estimates by Mak and Mason (7) (this cost includes the cost of replacing the pole after 10 years due to weakening the pole; thus a 20-year life is assumed with this cost).

No roadside adjustment factor is involved in the B/C equations for breakaway devices because the poles in the after condition are assumed to be in the same location as the before condition. Thus no change in other types of run-off-road accidents is expected.

If breakaway poles only reduce 30 percent of injury and fatal accidents, they would be cost effective only in a few extreme situations, such as for sections with traffic volumes of 20,000 or more with pole offsets of 2 ft (0.6 m) or less, and less than 60 poles per mile exist (37 poles/km). For a 60 percent reduction in injury and fatal accidents, breakaway poles are cost effective for traffic volumes as low as 5,000 or 10,000, depending on pole offset and pole density (see Table 9). These values are based on expected frequencies of utility pole accidents for various roadway conditions. A reduction of 60 percent of injury and fatal accidents is an optimistic expectation from a breakaway pole, and this reduction may not be achievable with existing breakaway pole treatments.

GUIDELINES FOR SELECTING COST-EFFECTIVE COUNTERMEASURES

The analysis results were compiled into a format to allow a user to quickly determine what countermeasures are generally cost effective for site-specific conditions. Such guidelines would also be useful in selecting countermeasures to be more formally evaluated. The guidelines contained in this section are for urban and rural divided and undivided roadways; the results do not include freeways or other full-access control roadways. The following guidelines are intended to help the user to scope the problem and to select countermeasures that are likely to be cost effective. Recall that these cost-effectiveness analyses are based partly on a set of average conditions and a few basic assumptions. Thus a more site-specific analysis is also needed for each proposed treatment at a site to determine which countermeasures are cost effective.

However, for the set of average conditions dis-

TABLE 9 Summary of B/C Ratios for Breakaway Poles for Various Roadway Conditions, Assuming 30 and 60 Percent Reductions in Injury and Fatal Accidents

Pole Offset (Feet)	ADT	Assuming a 30% Reduction in Injury and Fatal Accidents: Pole Density (Poles/Mile) 30	50	70	Assuming a 60% Reduction in Injury and Fatal Accidents: Pole Density (Poles/Mile) 30	50	70
2	1,000	0.45	0.44	0.44	0.65	0.64	0.64
	5,000	0.61	0.54	0.51	0.88	0.78	0.74
	10,000	0.81	0.66	0.59	1.17	0.96	0.86
	20,000	1.21	0.90	0.76	1.76	1.30	1.11
	40,000	2.01	1.38	1.11	2.92	2.00	1.61
	60,000	2.81	1.86	1.45	4.08	2.70	2.11
5	1,000	0.25	0.25	0.25	0.36	0.36	0.36
	5,000	0.34	0.30	0.29	0.49	0.44	0.42
	10,000	0.45	0.37	0.34	0.66	0.54	0.49
	20,000	0.69	0.51	0.44	1.00	0.74	0.63
	40,000	1.15	0.79	0.63	1.67	1.15	0.92
	60,000	1.61	1.07	0.83	2.34	1.55	1.21
10	1,000	0.15	0.16	0.16	0.22	0.23	0.23
	5,000	0.21	0.19	0.19	0.31	0.28	0.27
	10,000	0.29	0.24	0.22	0.42	0.35	0.32
	20,000	0.44	0.33	0.28	0.64	0.48	0.41
	40,000	0.75	0.51	0.41	1.09	0.75	0.60
	60,000	1.05	0.70	0.55	1.53	1.01	0.79
15	1,000	0.12	0.12	0.12	0.17	0.18	0.18
	5,000	0.16	0.15	0.14	0.24	0.22	0.21
	10,000	0.22	0.19	0.17	0.32	0.27	0.25
	20,000	0.34	0.26	0.22	0.50	0.37	0.32
	40,000	0.58	0.40	0.32	0.85	0.58	0.47
	60,000	0.82	0.54	0.43	1.19	0.79	0.62

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

cussed previously, a summary of cost-effective countermeasures for telephone poles in urban areas is shown in Figure 1. A series of matrix cells has been formed for various combinations of pole offset, pole density, and traffic fixed-object coverage. Within each matrix cell are letters or symbols that correspond to countermeasures that are cost effective based on average countermeasure costs, expected utility pole accidents, and countermeasure effectiveness. Most of the matrix cells in the upper and right-hand corner on Figure 1 (i.e., corresponding to close pole offsets and high traffic volumes) contain at least one symbol. This is because roadway conditions with close pole offsets and high traffic volumes afford the highest potential for cost-effective solutions because of the relatively high expected number of utility pole accidents. For pole offsets of 2 ft (0.6 m) and traffic volumes of 40,000 to 60,000, virtually any of the utility pole countermeasures could be cost effective. To determine which one of the cost-effective countermeasures is optimal under a specific set of conditions, a more formal analysis with site-specific conditions should be used.

Note in a few instances that placing lines underground and multiple pole use are cost effective at existing pole offsets up to 20 ft (6 m) under high traffic volumes and low fixed-object coverage. However, few other countermeasures are cost effective for telephone poles with pole offsets of 10 ft (3 m) or more. Note that two levels of pole relocation are given. When relocation of poles to 10 ft is cost effective, an Ⓡ symbol is given. When poles must be relocated to 20 ft to be cost effective, an R symbol is given. For breakaway poles, a Ⓑ is given if breakaway poles are cost effective at the lower effectiveness level (30 percent reduction in injury and fatal accidents), and a B is given in the matrix cell if poles are cost effective at the higher effectiveness level (60 percent reduction in injury and fatal accidents). A blank matrix cell means that no countermeasure is cost effective. Note that categories of "clear, level roadside with 0 percent fixed object coverage" are given, which assume B/C ratios for reduction in utility pole accidents alone, and assume that no additional fixed object accidents will occur because of the countermeasure.

A summary of cost-effective countermeasures for telephone poles in rural areas is shown in Figure 2. Traffic volume categories are lower to reflect lower volumes in rural areas. Similar guidelines were developed for one-phase electric distribution lines in urban and rural areas and for three-phase distribution lines in urban and rural areas. No guidelines were given for transmission lines because no countermeasures were found to be cost effective for transmission lines within the limits of the analysis.

All costs assumed for these guidelines were average costs obtained from telephone and electric utility companies and assume that no additional right-of-way costs are involved. If average costs or accident experience deviate greatly from the assumptions for a particular site, then the general guidelines are not appropriate, and further analysis must be used to determine whether any countermeasure is cost effective. However, the guidelines provide a general overview of which countermeasures are likely to be cost effective under a variety of traffic and roadway conditions.

SUMMARY AND CONCLUSIONS

The purpose of this study was to develop a cost-effectiveness analysis procedure for the selection of alternative utility pole treatments. It involved a large-scale data-collection effort to quantify expected benefits and costs associated with the var-

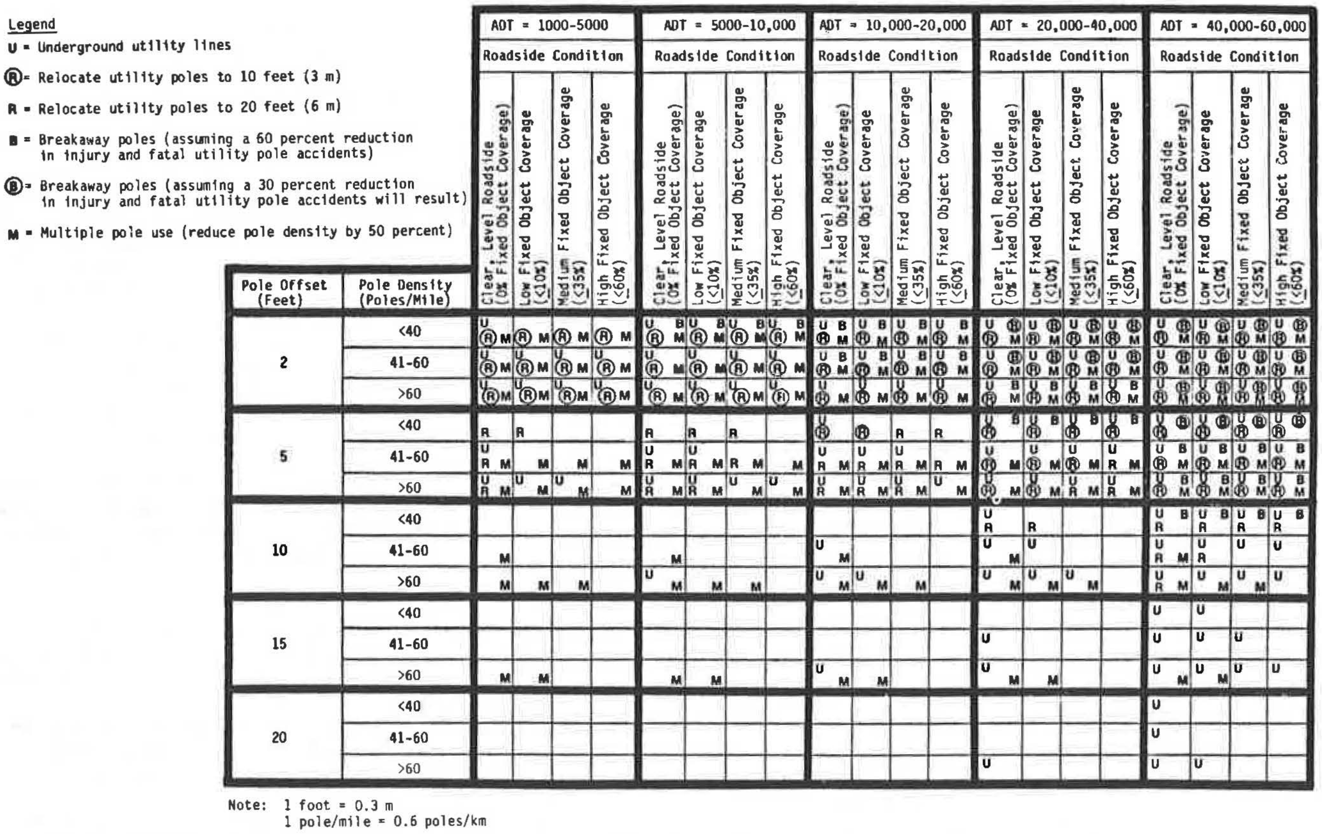

FIGURE 1 Guidelines for cost-effective countermeasures for utility pole accidents—telephone lines and poles in urban areas.

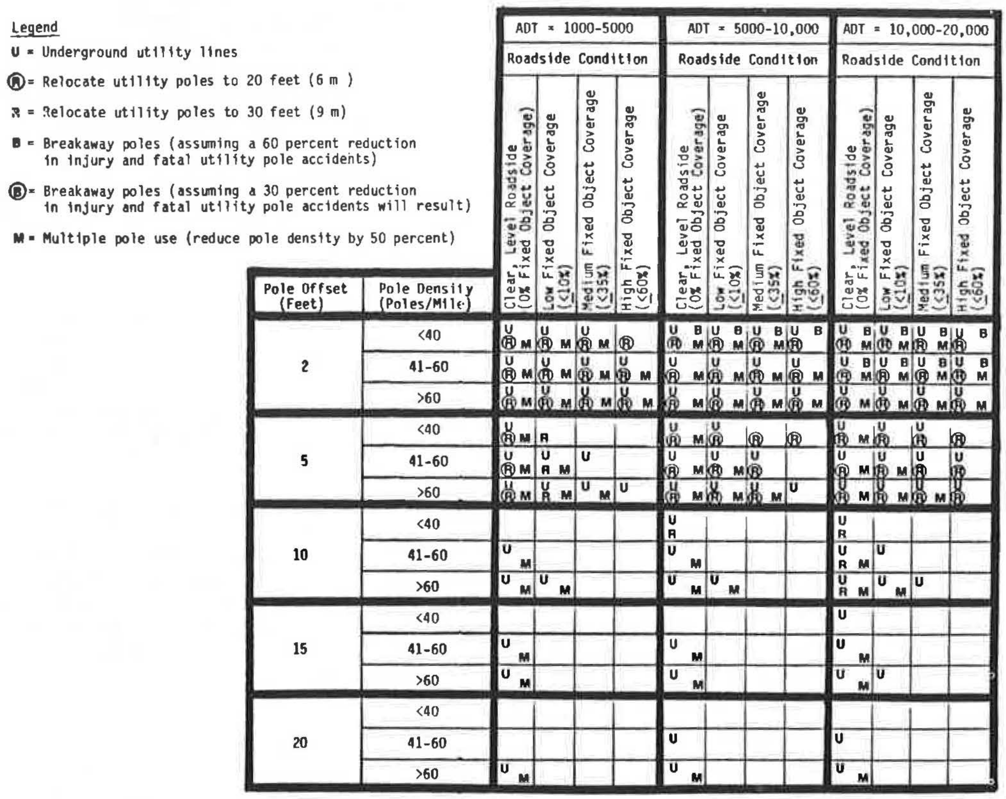

FIGURE 2 Guidelines for cost-effective countermeasures for utility pole accidents—telephone lines and poles in rural areas.

ious countermeasures. The following is a summary of the results of that study.

1. The variables that were of primary importance in explaining the variation in utility pole accident experience were traffic volume (average daily traffic), pole offset, and pole density. A model was developed to predict utility pole accident experience as a function of roadway and utility pole characteristics.

2. Based on average countermeasure costs and expected accident reduction for various situations, a cost-effectiveness analysis was conducted. By using 1981 NSC costs and the severity of utility pole accidents, the average cost of a utility pole accident was computed to be $7,007. The following is a summary of findings concerning each type of countermeasure investigated.

- -- No countermeasures are cost effective relative to large electric transmission lines because of the high costs associated with placing lines underground or relocating these poles.
- -- Placing lines underground is cost effective for many situations that involve telephone lines and electric distribution lines (less than 69 Kv), where direct burial of lines is possible. However, placing three-phase distribution lines underground is cost effective only under a few extreme situations. Placing lines underground is not cost effective in situations in which a conduit is required.
- -- Increasing lateral pole offset is cost effective in many situations, particularly for telephone poles, and to a lesser extent for electric distribution lines.
- -- Multiple pole use is cost effective in most situations in urban and rural areas with traffic volumes greater than 5,000, where poles are within 5 ft (1.5 m) of the roadway.
- -- Increasing pole spacing by as much as 20 percent is not cost effective under any situation analyzed.
- -- Breakaway pole devices are still being developed and tested, so their final effectiveness is not yet established. However, assuming a 30 percent reduction in injury and fatal accidents, breakaway poles are cost effective only for a few extreme situations. Assuming a 60 percent reduction in injury and fatal accidents, breakaway poles are cost effective under a variety of conditions of pole offset and traffic volume

3. General guidelines were developed for selecting cost-effective countermeasures for utility pole accidents under a variety of traffic and roadway conditions. A user can also conduct a more site-specific cost-effectiveness analysis by using a series of figures to quickly select the countermeasures that are likely to be cost effective. The user should then select the optimal project alternative from two or more cost-effective countermeasures based on the incremental B/C ratio or other accepted methods. The guidelines and cost-effectiveness procedures in this paper apply to divided and undivided roadways and to urban and rural areas and should only be used for roadways with traffic volumes of 1,000 to 60,000, pole offsets of 2 to 30 ft (0.6 to 9 m), and pole densities of about 10 to 90 poles per mile (6 to 56 poles/km). The guidelines do not apply to freeway sections or to sections with poles in the median.

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