Methodology for Evaluation of Safety Improvement Alternatives for Utility Poles

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The object of this paper is to present the formulation and demonstration of a methodology for evaluation of safety improvement alternatives for utility poles. It is a total-annual-cost method of economic analysis, which features the calculation of expected annual accident and collision maintenance costs on the probabilities and severities of single-vehicle collisions with utility poles and other fixed objects on the roadside. The probabilities and severities of these collisions are in turn computed from a definition of the speed and volume of traffic, distribution of vehicle sizes, and the numbers, types, and locations of utility poles and other fixed objects on the roadside. The methodology can be used to evaluate several types of improvement alternatives, including multiple use of poles, relocation of poles, breakaway poles, impact-attenuation systems, and underground placement of utility lines. It can also be used to evaluate alternatives for a specific situation or for various combinations of traffic and roadside conditions in order to identify the circumstances for which each is most economical. The methodology is demonstrated for various traffic and roadside conditions on two hypothetical street sections typical of many arterial street sections in Lincoln, Nebraska. The results of this demonstration show the applicability of the methodology and serve to illustrate the sensitivity of the selection of the best alternative to traffic and roadside conditions.

The serious accident problem associated with the location of utility poles close to the edge of roadways, particularly in urban areas, has been the subject of considerable research in recent years. Some studies have been concerned with the nature and extent of the problem, whereas others have concentrated on developing various countermeasures. But few studies have been directed at determining the cost-effectiveness of alternative countermeasures (1).

During the past year, the Civil Engineering Department at the University of Nebraska--Lincoln has been conducting research on the design and testing of a breakaway-pole concept for wooden utility poles (2). As part of this research, a methodology was developed for evaluating various safety improvement alternatives for utility poles. It has been used during the conduct of the research to compare the concept being developed with other countermeasures in order to define the concept's cost limits of economic feasibility for various traffic and roadside conditions.

The methodology developed computes the total annual cost of an alternative, which includes its capital recovery and annual maintenance costs plus the expected annual cost of accidents between a single vehicle and a fixed object on the roadside. Based on a description of the speed and volume of traffic and the size, location, and type of fixed objects along the roadway, the probabilities and severities of single-vehicle collisions with the fixed objects are computed. The accident costs of these collisions are then computed and added to the capital recovery and annual maintenance costs of the improvement alternative. By comparing the total annual costs of the alternatives and the existing condition, the most economical course of action is identified. The methodology can be used to evaluate a specific case or it can be used to evaluate the total annual cost of various alternatives over a range of traffic and roadside conditions to identify the circumstances for which each would be most economical.

This paper presents a description of the formulation of the methodology. Also included are the results of a demonstration of its application, in which the total annual costs of a number of safety improvement alternatives were compared for various traffic and roadside conditions typical of some arterial streets in Lincoln, Nebraska. The alternatives evaluated were (a) relocating the utility poles to increase their lateral distance from the edge of the roadway, (b) retrofitting the utility poles to make them break away when hit, and (c) placing the utility lines underground.

FORMULATION

The methodology developed is basically the conventional annual-cost method of analyzing alternatives, in which the total annual costs of the existing condition and the alternatives are computed and compared to identify the one with the lowest annual cost. The total annual cost of an alternative or the existing condition is computed (in dollars per year) as follows:

$$\Sigma C = A + C + NMC + CMC \qquad (1)$$

where

- ΣC = total annual cost of improvement alternative or existing condition,
- A = expected annual accident cost of improvement alternative or existing condition,
- C = capital recovery cost of improvement alternative or existing condition,
- NMC = annual normal maintenance cost of improvement alternative or existing condition, and
- CMC = annual collision maintenance cost of improvement alternative or existing condition.

The distinguishing feature of the methodology is the computation of expected accident costs and collision-maintenance costs based on probabilities and severities of potential single-vehicle collisions with fixed objects (including utility poles) on the roadside. A description of the calculation of these costs follows.

Accident Costs

The general equation used to compute the expected annual accident cost of an improvement alternative or existing condition is as follows:

$$A = E\Sigma_{\theta v}\Sigma\{P(E_{\theta,v}/E)\Sigma_w[P(w)\Sigma_F P(C_{\theta,v}^{w,F}/E_{\theta,v})(AC_{\theta,v}^{w,F})]\} \qquad (2)$$

where

- A = expected annual accident cost (dollars per year);
- E = encroachment rate (number of roadside encroachments per mile per year);
- $P(E_{\theta,v}/E)$ = probability of an encroachment at angle θ and speed v given that an encroachment has occurred $[\Sigma_{\theta v}\Sigma P(E_{\theta,v}/E) = 1.0]$;
- $P(w)$ = decimal fraction of vehicles of size w in traffic stream $[\Sigma_w P(w) = 1.0]$;
- $P(C_{\theta,v}^{w,F}/E_{\theta,v})$ = probability of a collision at angle θ and speed v of a vehicle of

size w with a fixed object of type F given an encroachment at angle θ and speed v;

$AC^{w,F}_{\theta,v}$ = accident cost of a collision at angle θ and speed v of a vehicle of size w with a fixed object of type F;

θ = encroachment and collision angle (°);

v = encroachment and collision speed (mph);

w = vehicle size designation, which defines width and weight of vehicle; and

F = fixed-object type designation, which defines size and impact severities of fixed object.

In Equation 2, the effect of an improvement alternative or existing condition is determined by the probability and severity of collision terms $[P(C^{w,F}_{\theta,v}/E_{\theta,v})$ and $AC^{w,F}_{\theta,v}]$. These and the other variables in this equation are described below.

Encroachment Rate

Knowledge of the rate at which vehicles encroach on the roadside of various types of roadways is very limited. In fact, the only pure encroachment data available are those of Hutchinson and Kennedy (3), which were collected on freeway medians. More recently, Glennon and Wilton (4) have estimated encroachment rates for different classes of roadways as linear functions of average daily traffic (ADT). These relationships, which were derived from an analysis of roadside accident rates for various classes of roadways and a comparison of the freeway encroachment rate determined by Hutchinson and Kennedy with the roadside accident rate on freeways in Missouri, are presented below. (It should be noted that these encroachment rates are for the total number on both sides of the roadway; therefore, if only one side of a roadway is being considered, as is often the case with utility poles, the rate should be divided by 2.)

Class of Roadway	Encroachment Rate (no./mile/year)
Rural highway	
Interstate	0.000 9
Multilane divided	0.000 59
Wide two-lane (roadbed ≥36 ft)	0.000 742
Narrow two-lane (road <36 ft)	0.001 21
Urban highway	
Interstate	0.000 9
Multilane divided	0.000 9
Major arterial street	0.001 33

Probabilities of Combinations of Encroachment Angle and Speed

As in the case of encroachment rates, knowledge of the probabilities of combinations of encroachment angle and speed is also extremely limited. Therefore, for purposes of developing the methodology, these probabilities are computed by combining the distributions of encroachment angles and traffic speeds as follows:

$$P(E_{\theta,v}/E) = P(E_\theta/E)P(v) \quad (3)$$

where $P(E_\theta/E)$ is the probability of an encroachment at angle θ given that an encroachment has occurred $[\Sigma_\theta P(E_\theta/E) = 1.0]$ and P(v) is the probability of a vehicle speed v in the traffic stream $[\Sigma_v P(v) = 1.0]$. Thus, encroachment speed is assumed to be equal to the traffic speed on the roadway and independent of encroachment angle. Of course, the point-mass model presented by Ross (5) indicates that some high-angle high-speed encroachments are not possible. However, because of the lack of encroachment data to support this theory and because of their low probabilities of occurrence, no adjustment is made to account for the apparent impossibility of high-angle high-speed encroachments.

In the methodology, the range of encroachment angles is divided into six intervals. The interval probabilities, which were derived from the encroachment-angle distribution reported by Hutchinson and Kennedy (3), are presented below. The encroachment angle is assumed to be independent of vehicle size and type of roadway.

Encroachment Angle (°)	Probability
<7.5	0.48
7.5-12.5	0.20
12.5-17.5	0.12
17.5-22.5	0.08
22.5-27.5	0.05
>27.5	0.07

Encroachment speeds are assumed to be normally distributed; the standard deviation is ±5.0 mph, which is representative of many roadways (6). The range of encroachment speeds is divided into five intervals based on the speed limit on the roadway. The probabilities of speeds within these intervals, based on the assumption that the speed limit (S) is equal to the 85th-percentile speed, are presented below. Encroachment speeds are also assumed to be independent of vehicle size.

Encroachment Speed (mph)	Probability
<(S - 12.5)	0.07
(S - 12.5) to (S - 7.5)	0.25
(S - 7.5) to (S - 2.5)	0.39
(S - 2.5) to (S + 2.5)	0.23
≥(S + 2.5)	0.06

Thus, in the methodology, 30 combinations of encroachment angle and speed are evaluated for each combination of vehicle size and fixed-object type.

Vehicle Size Probabilities

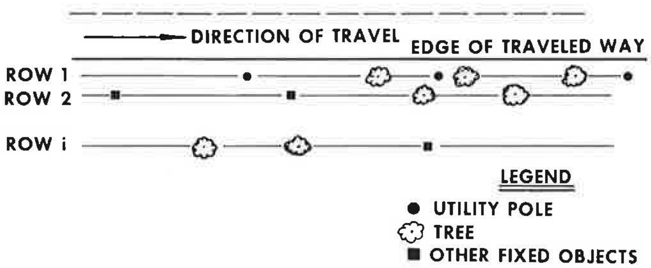
The probabilities and severities of single-vehicle collisions with fixed objects on the side of a roadway are dependent on the size of the encroaching vehicles. In general, the wider an encroaching vehicle is, the greater the probability is that it will collide with a fixed object on the roadside. Likewise, the smaller a vehicle is, the greater the severity of its collision will be with a fixed object. Therefore, the methodology developed in this research is designed to account for these effects of vehicle size.

The encroachment rates are assumed to be independent of vehicle size. Therefore, the probability that an encroaching vehicle will be of a particular size is assumed to be equal to the decimal fraction of vehicles of that size in the traffic stream.

Collision Probabilities

The probability that an encroaching vehicle will collide with a fixed object on the side of the roadway depends on (a) the number, size, and location of the fixed objects on the roadside and (b) the width

Figure 1. Idealization of roadside.



of the encroaching vehicle and the angle of its encroachment. In general, the more fixed objects there are along the roadside, the greater the probability of a collision will be.

To facilitate the formulation of this methodology, the description of the roadside is idealized in terms of rows and types of fixed objects as illustrated in Figure 1. The designation of each type of fixed object defines the size and severities of collision with a particular type of fixed object. For example, nonbreakaway utility poles 1 ft in diameter would be one type of fixed object that might be found on the roadside. Since the subject of this study is utility poles, they are the type of fixed objects that are of the greatest concern. However, other types of fixed objects cannot be ignored, because their sizes and locations could reduce the probability of a collision with a utility pole. In general, the greater the number of other fixed objects on the roadside is, the lower the probability of colliding with a utility pole is.

The equation derived for computing the collision probability is as follows:

$$P(C^{w,F}_{\theta,v}/E_{\theta,v}) = \sum_{i=1}^{n} P_i(C^{w,F}_{\theta,v}/E_{\theta,v}) \cdot P_{i-1}(NC^{w}_{\theta,v}/E_{\theta,v}) \cdot P_{i-2}(NC^{w}_{\theta,v}/E_{\theta,v}) \ldots P_o(NC^{w}_{\theta,v}/E_{\theta,v}) \qquad (4)$$

where

$P_i(C^{w,F}_{\theta,v}/E_{\theta,v})$ = probability of a collision at angle θ and speed v of a vehicle of size w with a fixed object of type F in row i given an encroachment at angle θ and speed v,

$P_i(NC^{w}_{\theta,v}/E_{\theta,v})$ = probability of no collision at angle θ and speed v of a vehicle of size w with a fixed object of any type in row i given an encroachment at angle θ and speed v $[P_i(NC^{w}_{\theta,v}) = 1 - \Sigma_F P_i(C^{w,F}_{\theta,v}/E_{\theta,v})]$,

$P_o(NC^{w}_{\theta,v}/E_{\theta,v})$ = 1.0, and

n = number of rows of fixed objects.

The probability of a collision with a fixed object in one row is dependent on the probability that an encroaching vehicle will not collide with a fixed object in a preceding row (i.e., a row closer to the roadway). However, given that an encroaching vehicle has not collided with a fixed object in a preceding row, the probability that it will collide with a particular type of fixed object in row i is the product of two other conditional probabilities:

$$P_i(C^{w,F}_{\theta,v}/E_{\theta,v}) = P_i(X^{w,F}_{\theta,v}/E_{\theta,v})P_i(C^{w,F}_{\theta,v}/X^{w,F}_{\theta,v}) \qquad (5)$$

where $P_i(X^{w,F}_{\theta,v}/E_{\theta,v})$ is the probability that the encroachment path of a vehicle of size w will intersect the location of a fixed object of type F in row i given an encroachment of angle θ and speed v, and $P_i(C^{w,F}_{\theta,v}/X^{w,F}_{\theta,v})$ is the probability that there will be a collision at angle θ and speed v of a vehicle of size w with a fixed object of type F in row i given that the vehicle is on an intersecting path at angle θ and speed v.

The conditional probability that an encroaching vehicle will be on a path that intersects the location of a fixed object of a particular type in row i is proportional to the length of the roadway within which this could occur. As illustrated in Figure 2, this length for a single fixed object is a function of the encroachment angle, the width of the vehicle, and the diameter of the fixed object. This relationship is defined by the following equation:

$$L^{w,F}_{\theta,v,i} = (d^F_i + y^w)\csc\theta \qquad (6)$$

where

$L^{w,F}_{\theta,v,i}$ = length of roadway within which encroachment path at angle θ and speed v of a vehicle of size w would intersect the location of a single fixed object of type F in row i (ft),

d^F_i = diameter of fixed object of type F in row i (ft), and

y^w = width of encroaching vehicle of size w (ft).

However, if fixed objects in row i are close enough together, the presence of those upstream will screen those downstream, thus reducing the length of roadway within which the locations of those downstream could be intersected by encroaching vehicles. This reduction would be equal to the amount by which their roadway lengths overlap, as illustrated in Figure 3.

Due to a lack of data on the effects of roadway geometrics on the frequency and nature of encroachments, it is assumed that the distribution of encroachments along the length of a roadway is uniform. Therefore, the probability that a vehicle encroachment will be on a path that intersects the location of a fixed object in row i is as follows:

$$P_i(X^{w,F}_{\theta,v}/E_{\theta,v}) = (1/5280)\sum_{j=1}^{N_i}(L^{w,F}_{\theta,v,i,j} - O^{w,F}_{\theta,v,i,j}) \qquad (7)$$

where

N_i = number of fixed objects of type F per mile in row i,

$L^{w,F}_{\theta,v,i,j}$ = length of roadway within which encroachment path at angle θ and speed v of a vehicle of size w would intersect the location of the jth fixed object of type F in row i (ft), and

$O^{w,F}_{\theta,v,i,j}$ = portion of $L^{w,F}_{\theta,v,i,j}$ that overlaps with that of other fixed objects in row i upstream of the jth fixed object of type F in row i (ft).

The conditional probability $[P_i(C^{w,F}_{\theta,v}/X^{w,F}_{\theta,v})]$ that an encroaching vehicle on an intersecting path with a fixed object in row i will collide with that fixed object given that it has not collided with one in a preceding row is a function of the lateral distance

Figure 2. Length of roadway within which encroachment at angle θ would intersect location of fixed object.

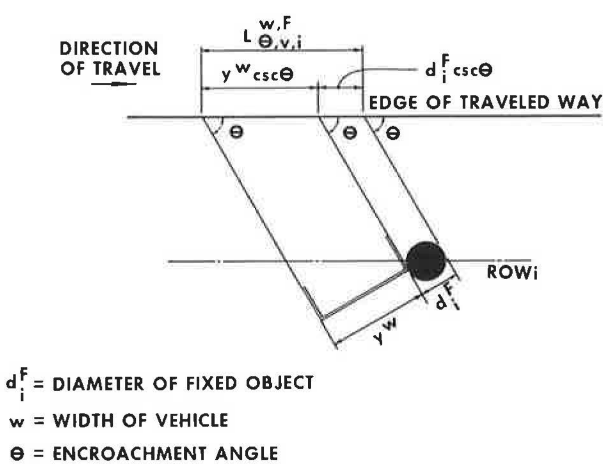
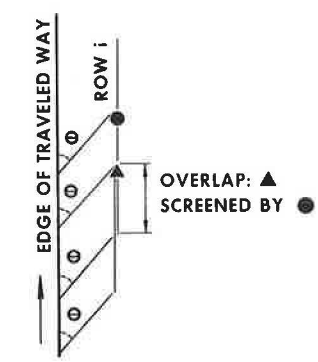


Figure 3. Illustration of screening effect.



between the edge of the traveled way and row i. The greater this distance is, the farther the vehicle must travel along its encroachment path to reach the fixed object and the less likely it is that it will collide with it. This conditional probability is determined from the appropriate distribution of lateral extent of encroachments shown in Figure 4. These distribution curves were derived from an analysis of the encroachment data reported by Hutchinson and Kennedy (3). It is assumed that these distributions are independent of encroachment speed and vehicle and are only dependent on the encroachment angle.

Collision Costs

The accident costs of a collision with a fixed object are computed as a function of the severity of the collision in terms of the probability that an injury accident would result. The relationship between accident costs and probability of an injury accident shown in Table 1 is the one used in the methodology developed in this study.

This relationship, developed by Post (7) in previous research, equates various levels of injury-accident probability with a percentage distribution of accident severities [i.e., percent fatal, percent nonfatal-injury, and percent property-damage-only (PDO) accidents]. The mean accident costs shown in Table 1 are computed by applying the percentage distributions to the following figures for unit accident cost: $150 000 per fatal accident, $5800 per nonfatal-injury accident, and $850 per PDO accident.

Figure 4. Distributions of lateral extent of encroachments.

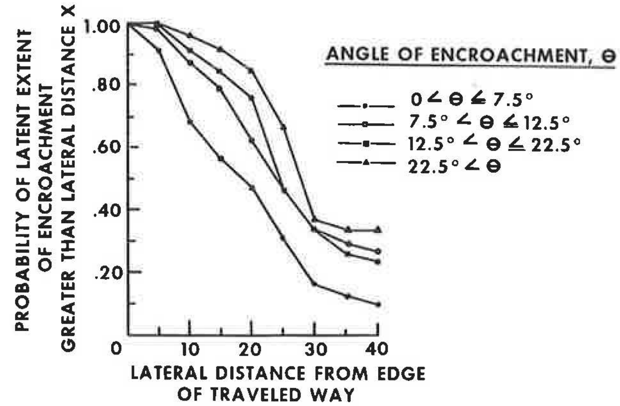


Table 1. Relationship between mean accident cost and injury-accident probability.

Injury-Accident Probability	PDO[a] Accidents (%)	Nonfatal-Injury Accidents (%)	Fatal Accidents (%)	Mean Accident Cost ($)
0.1	90	10	0	1 400
0.3	60	40	0	2 300
0.5	40	60	0	3 820
0.7	10	88	2	8 190
0.8	0	96	4	11 570
1.0	0	94	6	14 450

[a]PDO = Property damage only.

The probability that a collision with a fixed object will result in an injury accident is a function of the angle and speed of impact, the size of the vehicle involved, and the type and size of fixed object struck. By using mathematical modeling and computer simulation, the probabilities of an injury accident were computed for collisions with breakaway (B) and nonbreakaway (N) wooden utility poles in research conducted at the University of Nebraska (2). These values, presented below for a 4500-lb vehicle, were used in the demonstration of the methodology presented in this paper. Similar relationships can be developed for other types of fixed objects. However, for an in-depth discussion of the derivation of such relationships, the reader is referred to a study by Post and others (8).

Vehicle Impact Speed (mph)	Probability of Injury Accident B	N
10	0.19	0.28
15	0.28	0.45
20	0.42	0.59
25	0.57	0.74
30	0.62	0.89
35	0.62	1.00

Other Costs

When the methodology presented in this paper is applied, the capital recovery and maintenance costs in Equation 1 should be based on local unit costs and interest rates. Also, the collision maintenance cost of an improvement alternative or existing condition is computed in the same way as the accident cost is computed except that, in using Equation 2, the term for collision accident cost

($AC^{w,F}_{\theta,v}$) is replaced with a term for collision maintenance cost, as follows:

$$CMC = E\,\Sigma_\theta\,\Sigma\{P(E_{\theta,v}/E)\,\Sigma_w[P(w)\,\Sigma_F\,P(C^{w,F}_{\theta,v}/E_{\theta,v})(CM^{w,F}_{\theta,v})]\} \quad (8)$$

where CMC is the expected annual collision maintenance cost (in dollars per year) and $CM^{w,F}_{\theta,v}$ is the maintenance cost of a collision at angle θ and speed v of a vehicle of size w with a fixed object of type F. Depending on the amount of knowledge the user of the methodology has regarding the collision maintenance cost of the improvement alternative or existing condition, the term for collision maintenance cost in Equation 8 could be an average collision maintenance cost for all collisions or it could be related to the severity of the collision as is the term for collision accident cost.

DEMONSTRATION

To demonstrate the use of the methodology presented in this paper, it was used to evaluate utility-pole safety improvement alternatives on two hypothetical sections of arterial street typical of several in Lincoln, Nebraska. Also, to illustrate the effects of traffic volume and number of other fixed objects on the relative costs of the alternatives, they were evaluated over a range of traffic and roadside conditions. A computer program was written and used to calculate the terms for collision accident and collision maintenance costs of the total-annual-cost equation (Equation 1). A description of the cases evaluated and the results of the evaluations follow.

Streets

The two street sections used in this demonstration were 1000 ft long. Each had utility poles on one side, which were uniformly spaced at 80-ft intervals and set back 2 ft from the edge of the traveled way. The utility poles were standard 40-ft, class 4 poles made of southern yellow pine. The injury-accident probabilities of collisions with these poles were assumed to be the same as those presented in the section on collision costs for nonbreakaway poles.

On one of the sections (street A), the fixed objects other than utility poles were located in the same row as the utility poles (i.e., 2 ft from the edge of the traveled way) and, on the other (street B), they were located in a row 10 ft from the edge of the traveled way. The numbers of fixed objects in these rows were varied from none to 20 (i.e., 0, 6, 13, and 20 fixed objects). In each case, the fixed objects were distributed at random throughout the 1000-ft length of the section. All fixed objects were assumed to be 1 ft in diameter, and they were assigned the same injury-accident probabilities as those for the nonbreakaway utility poles.

In all cases, the speed limit on the street was 35 mph, and all vehicles in the traffic stream were standard-sized passenger cars that were 6.5 ft wide and weighed 4500 lb. The encroachment rate used for a major urban arterial street was 0.001 33 accident per mile per year. The encroachment angle and speed probabilities used were those shown previously. The evaluations were conducted for two traffic volumes: 15 000 and 30 000 ADT.

Thus, on each of the two streets, eight cases were evaluated (i.e., four numbers of fixed objects times two traffic volumes).

Improvement Alternatives

For each of the eight cases on each street, the following three improvement alternatives were evaluated:

1. Breakaway: The utility poles were made to break away by applying the breakaway concept developed at the University of Nebraska--Lincoln (2). The utility poles were assigned the injury-accident probabilities given in the section on collision costs for breakaway poles, thus reducing the probability that a collision with a utility pole would result in an injury accident.
2. Relocate: The utility poles were moved 2-10 ft from the edge of the traveled way, thus reducing the probability of a collision with a utility pole.
3. Underground: The utility poles were removed and the utility lines were placed underground, thus eliminating collisions with utility poles.

The capital and maintenance cost data for the existing conditions and the improvement alternatives were provided by D. Redding, supervisor of transmission and substation of the Lincoln Electric System. The capital cost data are presented in Table 2. All alternatives were assumed to have 30-year service lives and zero salvage values, and a 10 percent interest rate was used. Also, the normal maintenance costs of alternatives were assumed to be the same, and the collision maintenance costs of the existing conditions and of the breakaway and relocation alternatives were all computed by using an average collision maintenance cost of $250 per collision. The collision maintenance costs computed by using Equation 8 are presented in Table 3 for 15 000 ADT (multiply these costs by 2 to obtain costs for 30 000 ADT). As noted, the collision maintenance costs for 30 000 ADT were twice those for 15 000 ADT because the encroachment rate is a linear function of ADT; therefore, there were twice as many collisions for 30 000 ADT.

RESULTS

The annual accident costs for 15 000 and 30 000 ADT are shown in Figure 5 (top and bottom, respectively). These costs include the accident costs of collisions with other fixed objects in addition to those of collisions with utility poles.

The number and location of utility poles on street A are the same as those on street B. Therefore, at a given traffic volume, the annual accident costs are the same on both streets when there are no fixed objects other than utility poles along the streets. However, when there are other fixed objects, the annual accident costs are higher on street A because the fixed objects on street A are closer to the edge of the traveled way and thus more likely to be struck by an encroaching vehicle. Likewise, on either street, as the number of fixed objects is increased, the accident costs increase because of the greater probability of collisions with fixed objects. Of course, at some point as the number of fixed objects is increased, the probability that an encroaching vehicle will be on a path that intersects the location of a fixed object reaches 1. At this point, the annual accident cost for a particular alternative is maximized.

In all cases, the existing condition has the highest annual accident cost, and the underground alternative has the lowest. However, on street A, the order of the other two alternatives with respect to annual accident cost reverses as the number of fixed objects is increased. With fewer fixed objects or with none, the relocation alternative has the lower annual accident cost. But with more fixed

Table 2. Capital cost data.

Alternative	Unit Cost ($)	First Cost ($)	Capital Recovery[a] Cost ($)
Existing	0	0	0
Breakaway	20/pole	260	30
Relocate	30 000/mile	5 700	630
Underground	18/ft	18 000	1950

[a]Capital recovery factor for 10 percent interest rate, 30-year service life, and zero salvage value = 0.11.

Table 3. Collision maintenance costs for 15 000 ADT.

Alternative	No. of Fixed Objects 0	6	13	20
Costs for Street A ($)				
Existing[a]	210	140	117	45
Breakaway[a]	210	140	115	45
Relocate[b]	170	105	75	45
Underground[c]	0	0	0	0
Costs for Street B ($)				
Existing[a]	210	210	210	210
Breakaway[a]	210	210	210	210
Relocate[b]	170	115	95	40
Underground[c]	0	0	0	0

[a]Utility poles located 2 ft from edge of traveled way.
[b]Utility poles located 10 ft from edge of traveled way.
[c]No utility poles.

objects, the breakaway alternative has the lower annual accident cost. This is because, when there are fewer fixed objects, the effect of the increased offset of the utility poles as in the relocation alternative is greater than the reduced collision severity is of utility poles as in the breakaway alternative. However, where there are more fixed objects, the probability that an encroaching vehicle will be on a path that intersects the location of a fixed object increases, which causes the screening of fixed objects by the utility poles to become the dominant factor. This favors the breakaway alternative because collisions with breakaway utility poles are less severe than are those with fixed objects.

However, on street B, the screening effect of utility poles is less significant because the fixed objects are located farther back from the edge of the traveled way. Consequently, on street B, the relocation alternative has a lower annual accident cost than the breakaway alternative does over the entire range of the number of fixed objects evaluated.

Also, in all cases, the annual accident costs for 30 000 ADT are twice those for 15 000 ADT. This is because the encroachment rate used is simply a linear function of ADT.

The total annual costs for 15 000 and 30 000 ADT are shown in Figure 6 (top and bottom, respectively). A comparison of the curves for total annual cost shown in Figure 6 indicates that the best alternative when there are 13 or fewer fixed objects is underground placement of utility lines. But as the number of fixed objects is increased, the increase in accident costs of fixed-object collisions offsets the effect of removing the utility poles. Thus, on street A, underground placement is no longer the lowest cost alternative, and breakaway poles become the best alternative due to the screening of fixed objects by the utility poles described earlier. However, on street B, this screening ef-

Figure 5. Annual accident costs for 15 000 (top) and 30 000 (bottom) ADT.

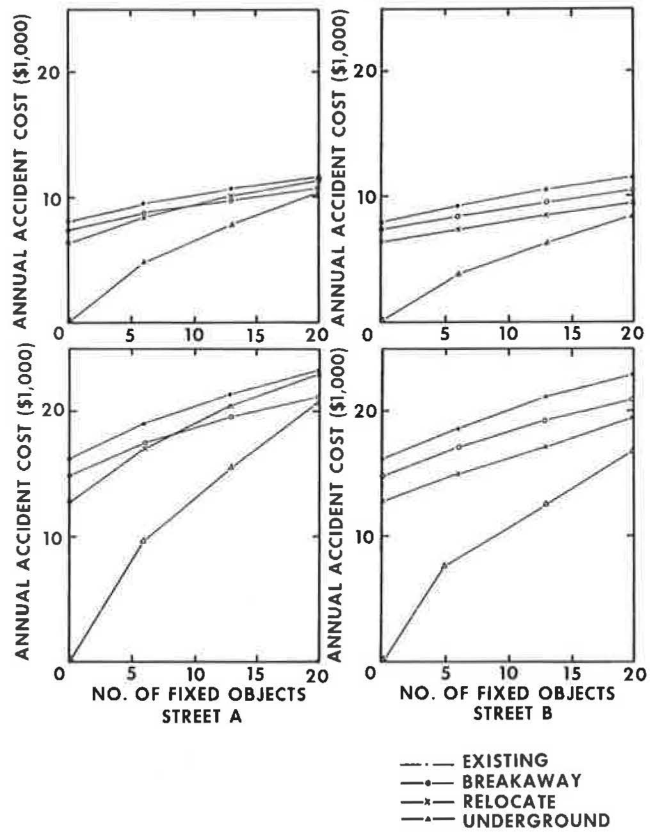
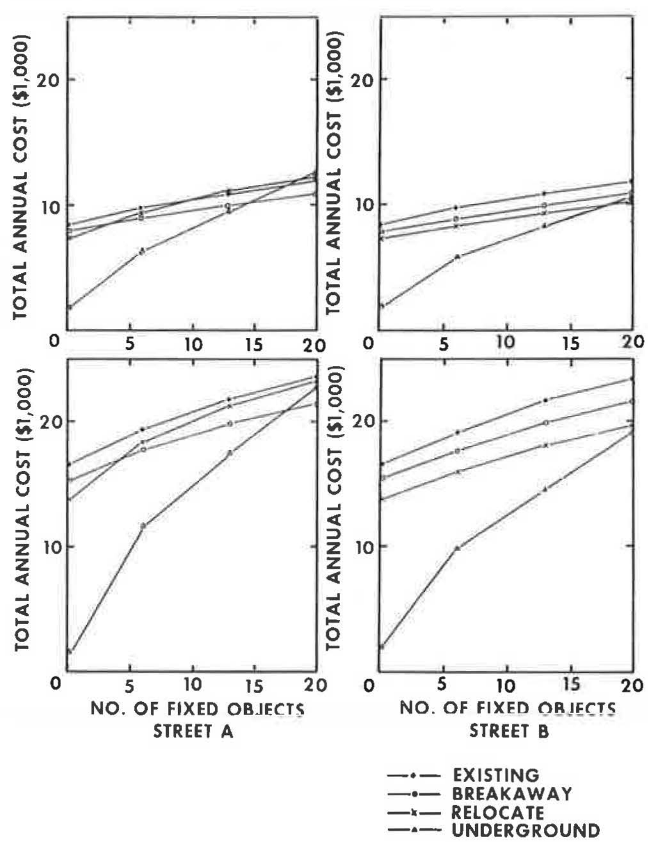


Figure 6. Total annual costs for 15 000 (top) and 30 000 (bottom) ADT.



fect is less significant because the fixed objects are farther from the edge of the traveled way. Therefore, underground placement is the best alternative for a greater number of fixed objects on street B.

The results shown in Figure 6 for 30 000 ADT show a similar best-alternative pattern. However, on street B, because of the higher annual accident costs, the effects of zero utility-pole accident costs by using underground placement are not offset as quickly with increased numbers of fixed objects. Thus, underground placement is the best alternative in all cases for 30 000 ADT on street B.

CONCLUSIONS

The demonstration of the methodology presented above indicates its applicability to a variety of improvement alternatives and various traffic and roadside conditions. Also, it illustrates the sensitivity of the selection of the best improvement alternative to traffic and roadside conditions. However, generalization concerning the relative economies of the alternatives should not be made on the basis of these results. It must be remembered that these results were for only one vehicle size, one utility-pole spacing, and one other type of fixed object, which was assumed to have the same collision properties as the nonbreakaway utility poles. Again, the purpose of the demonstration was not to identify the best alternatives for all conditions but to show the applicability of the methodology and some effects of traffic and roadside conditions on the relative economies of the alternatives. Also, although not described in this paper, the demonstration was conducted with the aid of a computer program of the methodology, which obviously facilitated the computations.

Finally, it should be noted that meaningful results from the use of the methodology require that local unit cost data be used. The costs used in the demonstration will most likely not be appropriate for other times and other places. Also, in the presentation of the formulation of the methodology, the results of research on the nature and frequency of roadside encroachments and collision severities, which are used in the calculation of accident and collision maintenance costs, were included. Their inclusion was primarily for the purpose of showing the nature of these factors and how they are incorporated within the methodology. However, the integrity of the methodology would not be compromised if the values of these factors were modified in accordance with the results of more recent (or future) research. In fact, such modifications should be made as more knowledge is gained.

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Abridgment

Loads on Bridge Railings

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Recent and ongoing research studies have addressed the problem of improving the performance of bridge-railing systems and extending the range of vehicles that can be restrained. This paper summarizes the results of one of these studies. A series of full-scale crash tests was completed that used several representative vehicle geometries and weights and an instrumented concrete barrier. The measured resultant loads, locations, and distributions are tabulated and discussed. Because the wall is relatively rigid—at least in comparison with most bridge railings—it is an obvious conclusion that the reported force magnitudes represent an upper limit. They are expected to be considerably smaller for collisions with more-compliant barriers. An equal corollary is that the contact duration will be longer.

The American Association of State Highway and Transportation Officials (AASHTO) Standard Specifications for Highway Bridges (1) sets forth design requirements for bridge railings. These requirements include limits on certain geometrics and set forth design loads. The basic load is a 10-kip static force applied at any location along the longitudinal axis of the railing; the vertical distribution depends on the railing configuration. The specifications further require that elastic structural analysis and design procedures be employed.