COST-EFFECTIVENESS ANALYSIS

of

ROADWAY LIGHTING SYSTEMS

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Research Report 137-1

Roadway Illumination Systems

Research Study Number 2-8-69-137

Sponsored by

The Texas Highway Department in

Cooperation with the

U. S. Department of Transportation

Federal Highway Administration

Bureau of Public Roads

June, 1969

TEXAS TRANSPORTATION INSTITUTE

TEXAS A&M UNIVERSITY

COLLEGE STATION, TEXAS

ABSTRACT

Research Study 2-8-69-137 was initiated to investigate and report cost-effectiveness relationships for various roadway lighting design criteria and roadway geometry. Five experimental roadway lighting designs were compared on a cost basis, with initial, maintenance, and accident costs as considerations.

Based on the cost information data presented in the study, conclusions were drawn as to the lighting designs most suitable for the various types of roadway configurations.

SUMMARY

Research Study 2-8-69-137 was initiated by the Texas Transportation Institute to investigate and report cost-effectiveness relationships for various roadway lighting design criteria and roadway geometry. The design criteria consisted of average illumination, average to minimum ratios of illumination, and maximum to minimum ratios of illumination. Facilities with four, six, eight, and ten traffic lanes comprised the roadway geometry configurations for analysis. Five alternatives were selected for consideration as effective lighting systems, based on the following three effectiveness measures:

1. A uniformity ratio of average to minimum illumination of not greater than 3 to 1.
2. A uniformity ratio of maximum to minimum illumination of not greater than 6 to 1.
3. Three levels of average illumination

   Level III - 1.25 foot-candles

   Level II - 1.00 foot-candles

   Level I - 0.75 foot-candles

The five designs designated as A, B, C, D, and E are described in the table which appears on the following page.

Vehicle accident predictions and statistics were calculated, based upon a method developed by Hutchinson and Kennedy. They indicated that placement of the illumination units and paths of the encroaching vehicles influence the number of vehicles that collide with the lighting poles. A vehicle's probability of hitting an illumination unit, provided its

DESCRIPTION OF ILLUMINATION ALTERNATIVES

Letter Used To Designate Alternative*	Unit Placement	Luminaire Wattage	Mounting Height (feet)	Unit Spacing (feet)
A(M-40-200)	Median	400	40	200
B(0-50-300)	One-Side	1000	50	300
C(M-50-300)	Median	1000	50	300
D(S-50-260)	Staggered	1000	50	260
E(S-50-300)	Staggered	1000	50	300

NOTE: Alternatives A and C with median placement have double arms and two luminaires. The other alternatives have single arms and one luminaire.

* The letters and numbers in parentheses refer to (Placement-Mounting Height in feet-spacing of units in feet); M refers to units placed in the median; 0 refers to units placed on one side of the roadway; S refers to units which are staggered, alternating on opposite sides of the roadway.

lateral distance of encroachment is not less than the distance that these units are from the pavement, is equal to 131.3 feet divided by the spacing, in feet, between illumination units.

Initial, maintenance, and accident costs were computed for 400-watt, 40-foot and 1000-watt, 50-foot units, for both 12-foot and 15-foot mast arms. Both "low" and "high" estimates were used to provide maintenance and accident information for periods of twenty and forty years. The findings of the study are based on the assumption that there is only one encroachment per mile per year for each 10,000 vehicles of two-way average daily traffic.

The conclusions of the study indicated that design B has the least expensive initial cost, followed by designs C, E, A, and D. Concerning maintenance costs, both designs B and E can be maintained equally at the lowest price.

The lowest accident costs are for designs B and E, based upon a particular average daily traffic volume and distance from the pavement edge.

The study also included comparisons among designs providing the three levels of average illumination for a given roadway configuration. For four-lane roadways, design B meets criteria III, whereas designs A and B satisfy criteria II and I. Design B is generally less expensive than design A. In planning six-lane facilities, both designs C and D satisfy Level III criteria. Design D, however, is less expensive than design C, unless C units are located in a rigid median barrier and a high volume of traffic is characteristic of the facility.

Design C meets the effectiveness criteria for Level III for use on eight-lane facilities. Design D qualifies for Levels II and I and is less expensive than design C. There are no accident costs, however, if design C units are located with a rigid median barrier. Design C is the only acceptable alternative for use on ten-lane roadways.

The study emphasized that flexibility of the various designs should be taken into consideration when planning a facility. If more travel lanes have to be added in the future, this change is design may alter the type of lighting system which would be most effective.

IMPLEMENTATION STATEMENT

In order to plan an effective roadway lighting system for a highway facility, several factors must be investigated. Intensity and uniformity ratios consisting of average illumination, average to minimum illumination, and maximum to minimum illumination are among those to be considered. The configuration of the roadway itself is also very important. These combined factors are evaluated to determine the lighting system providing the level of illumination necessary for a particular type of facility, but at the most economical cost. The results of this cost-effectiveness study, therefore, should provide the administrator and roadway lighting designer with very practical information for optimum decision-making. Although the alternatives discussed in the report are limited, similar techniques can be used to evaluate other options. The detailed techniques of evaluation and recommendations for potential applications are given in the conclusions and summary portions of the report.

INTRODUCTION AND OBJECTIVES

Introduction

Our "fifth freedom" - mobility - has given new stature to highway lighting. The advent of superhighways and wide-scale improvements in our street and highway system has brought about night traffic conditions that demand fixed lighting to insure safe and efficient traffic operation.

New roadway lighting systems are being installed almost daily. These installations represent very significant investments of public funds; therefore, care must be exercised to assure that the appropriate returns are being made to the taxpayer. This report represents an attempt to give the administrator and designer realistic guides for optimizing cost-effectiveness relationships for roadway lighting installations.

Objective

The objective of the research presented in this report is to investigate and report cost-effectiveness relationships for various roadway lighting design criteria and roadway geometry. Specifically, the objective includes consideration of the following:

A. Design Criteria

1. Average Illumination
2. Average to Minimum Ratio of Illumination
3. Maximum to Minimum Ratio of Illumination

B. Roadway Geometry

1. 4 Traffic Lanes (Total)
2. 6 Traffic Lanes (Total)

3. 8 Traffic Lanes (Total)

4. 10 Traffic Lanes (Total)

With completion of the objective, taking into consideration the above listed items, the lighting designer will be better able to select the lighting configuration for specific locations that optimize—i. e., secure maximum efficiency--returns on the investment.

EFFECTIVENESS CRITERIA AND ALTERNATIVES

Effectiveness Criteria and Alternatives

Three effectiveness measures were used in selecting feasible alternatives: (1) A uniformity ratio of average illumination to minimum illumination of not greater than 3 to 1, (2) A uniformity ratio of maximum illumination to minimum illumination of not greater than 6 to 1, (3) Three different levels of average illumination: Level III, 1.25 horizontal foot-candles; Level II, 1.00 horizontal foot-candles; and Level I, 0.75 horizontal foot-candles. There are, then, three levels of effectiveness, or three design criteria, as summarized in Table 1.

Table 2 gives the five basic alternatives which are compared in the conclusions of the report. In the table, the alternatives are given letter designations which are used throughout the report.

Table 3 shows the illumination alternatives which give stipulated levels of effectiveness for roadways with different numbers of lanes. For a given number of lanes, some alternatives meet more than one design criterion.

TABLE 1

LEVELS OF EFFECTIVENESS BY DESIGN CRITERIA LEVEL

Effectiveness Measure	Effectiveness by Design Criteria Number		
	I	II	III
Average Illumination (ft-C)	.75	1.00	1.25
Uniformity, Average to Minimum	3 to 1	3 to 1	3 to 1
Uniformity, Maximum to Minimum	6 to 1	6 to 1	6 to 1

TABLE 2

DESCRIPTION OF ILLUMINATION ALTERNATIVES

Letter Used To Designate Alternative*	Unit Placement	Luminaire Wattage	Mounting Height (feet)	Unit Spacing (feet)
A(M-40-200)	Median	400	40	200
B(0-50-300)	One-Side	1000	50	300
C(M-50-300)	Median	1000	50	300
D(S-50-260)	Staggered	1000	50	260
E(S-50-300)	Staggered	1000	50	300

NOTE: Alternatives A and C with median placement have double arms and two luminaires. The other alternatives have single arms and one luminaire.

* The letters and numbers in parentheses refer to (Placement-Mounting Height in feet-spacing of units in feet); M refers to units placed in the median; 0 refers to units placed on one side of the roadway; S refers to units which are staggered, alternating on opposite sides of the roadway.

TABLE 3

ILLUMINATION ALTERNATIVES WHICH MEET DIFFERENT DESIGN CRITERIA FOR ROADWAYS WITH DIFFERENT NUMBERS OF TRAFFIC LANES

Number of Traffic Lanes	Alternatives Meeting This Criteria by Criteria Number *		
	I	II	III
4	A,B	A,B	B
6	A,B,E	A,B	C,D
8	C,D	C,D	C
10	C	C	C

*For description of Criteria I, II, and III, see Table 1. For description of Alternatives A, B, C, D, and E, see Table 2.

ACCIDENT RATE PREDICTIONS

Accident Rate Predictions

This section presents a method of predicting the number of vehicles which might be expected to collide with illumination units. The number of collisions are predicted for the five alternative designs with different traffic volumes and for placement of the illumination units at different lateral distances from the roadway.

To predict the number of vehicles which will hit light supports per mile of roadway per year, it is necessary to have estimates of (1) the number of vehicles which run off the road, out of the prescribed traffic lanes, per mile per year, (2) the paths of vehicles after they run off the road, and (3) the location of light supports with respect to the prescribed travel lanes.

Hutchinson and Kennedy[1] give information on median "encroachment" rates and vehicle paths. A median encroachment is defined by them as "the travel of vehicle outside the designated lane(s) of travel and onto the median." They found that there was approximately one median encroachment per mile per year for each 2,000 vehicles of two-way average daily traffic. Their study covered divided highways, without lighting, in rural areas. Their encroachment rates are probably higher than the rates which should be used in this study for predicting vehicle-lighting installation accidents for at least three reasons: (1) Some of their encroachments were probably intentional and also under control to an extent such that the driver could avoid hitting a lighting installation. (2) The roadways considered for comparison in the report will all be lighted, therefore, it might be expected that night encroachment rates would be lower. (3) Some vehicles might be expected to hit other objects and, as a result, stop before reaching a lighting installation. For these reasons, it is assumed in the remainder of the report that there is only one median encroachment per mile per year for each 5,000 vehicles of two-way average daily traffic. It is also assumed that there is one non-median (i. e., off the right side of the road) encroachment per mile per year for each 5,000 vehicles of two-way average daily traffic; it is further assumed that half of these non-median encroachments occur in each direction. Thus, for non-median encroachments on only one side of a two-way highway, there is only one encroachment per mile per year for each 10,000 vehicles of two-way average daily traffic. It might be noted that for some median encroachments the same vehicle will also make a non-median encroachment. For example, in the study by Hutchinson and Kennedy, it was found that some vehicles left the roadway to the right and crossed back into the median and vice versa. On the two principal highways studied by Hutchinson and Kennedy, there were 328 median encroachments, and in 12 cases the vehicle left the roadway to the right, prior to making a median encroachment.

Encroachment rates are probably unlike for different highway facilities of differences in pavement types, road geometrics, weather, traffic composition, traffic speeds, and other driver, vehicle, roadway, or environmental conditions. Thus, the assumptions regarding encroachment rates may not be valid for every roadway. By making an assumption regarding such rates, however, it is possible to obtain meaningful estimates for comparing alternative designs.

Hutchinson and Kennedy indicate that there were more encroachments by vehicles driving into the afternoon sun. This would seem to indicate that, if illumination units are to be placed on only one side ("house side") of a facility, it should be the side opposite the vehicles traveling in the direction of the afternoon sun.

Hutchinson and Kennedy gave information on the paths of encroaching vehicles. The average angle at which encroaching vehicles left the pavement was 11 degrees. The distribution of the maximum lateral distances that encroaching vehicles travel from the edge of the pavement closely approximates a normal distribution, with a mean of 23 feet and a standard deviation of 11 feet, for maximum lateral distances of less than 40 feet. Table 4 was constructed on the basis of this information. These researchers indicated, for example, that about 90 percent of all encroaching vehicles would travel a lateral distance of at least 10 feet. Only 25 percent would travel a maximum lateral distance of at least 30 feet from the edge of the pavement.

The next question that arises is whether a vehicle that encroaches a lateral distance sufficient to hit a lighting installation will, in fact, hit such an installation. The proportion of encroaching vehicles which actually hit illumination units, assuming the units are "unprotected," depends upon the paths of encroaching vehicles and the placement of lighting poles. In other words, given that illumination units are placed, approximately 20 feet from the edge of the pavement, it is evident that about 35 percent of the encroaching vehicles will not hit

TABLE 4

APPROXIMATE PROBABILITY THAT ENCROACHING VEHICLE WILL EQUAL OR EXCEED CERTAIN LATERAL DISTANCES

Maximum Lateral Movement (feet)	Approximate Probability That Encroaching Vehicle Will Equal or Exceed Given Lateral Movement
10	.90
20	.65
25	.45
30	.25

a unit because their maximum lateral movement is less than 20 feet. However, the concern should be for the 65 percent of the encroaching vehicles which travel a lateral distance equal to or greater than the distance that illumination units are from the pavement.

In general, the probability that such a vehicle will collide with a pole can be approximated as the ratio of two distances. The distance in the numerator of the ratio is the average longitudinal distance covered by the path of the vehicle along a line between lighting units; that is, a line parallel to the pavement at a lateral distance from the pavement, equal to the distance that lighting units are placed from the pavement. Assuming the encroaching vehicle travels in a straight path, this distance can be approximated as twice the width of the path of the vehicle divided by the sine of the angle of encroachment. It is assumed that the width of the vehicle path is 12.5 feet (taken as an average of vehicle width and length). It is further assumed that all vehicles leave the pavement at an eleven-degree angle; this is the average encroachment angle found by Hutchinson and Kennedy in their study. Using 12.5 feet as the width of the vehicle path, and an eleven-degree encroachment angle, a distance is obtained for the numerator of the ratio as 131.3 feet. The distance in the denominator is the spacing between illumination units; for the alternatives considered in this analysis, this distance is 200 feet, 260 feet, or 300 feet.

In summary, it is estimated that the probability that a vehicle will hit an illumination unit, given that its lateral distance of encroachment is not less than the distance that such units are from the pavement, is equal to 131.3 feet divided by the spacing, in feet, between illumination units. It is emphasized that this calculation is based on several simplifying assumptions. The probabilities do have, however, the logical property that they are lower for longer spacings between illumination units. These probabilities are summarized in Table 5. It should perhaps be pointed out that for spacings of less than 131.3 feet, calculations would give a probability of greater than one; therefore, in terms of probabilities, this formulation does not hold for spacings less than 131.3 feet. It does indicate, however, that for short spacings many vehicles will hit more than one unit, if the deceleration is not sufficiently increased or the vehicle is not redirected. It is, of course, possible for one vehicle to hit two or more units with spacings greater than 131.3 feet. Using the simplified theory discussed above however, this is not theoretically possible.

The probabilities given in Tables 4 and 5 are used to derive the probabilities in Table 6. The probabilities in Table 6 are related to both the spacing of illumination units and the lateral distance that such units are from the edge of the traffic lane. For example, if units are placed 10 feet from the near pavement and are spaced 200 feet apart, the probability that a vehicle encroaching off the side of the pavement nearest the lighting poles will strike a unit is 0.594. This is obtained by multiplying the probability for a lateral distance of 10 feet (.90) from Table 4 by the conditional probability for spacings of 200 feet (.66) from Table 5.

Another way of interpreting the values in Table 6 is as the average

TABLE 5

CONDITIONAL PROBABILITY THAT VEHICLE ENCROACHING SUFFICIENT DISTANCE WILL HIT ILLUMINATION UNIT, BY SPACING

Illumination Unit Spacing (feet)	Conditional Probability That Vehicle Which Encroaches By Sufficient Lateral Distance Will Hit Illumination Unit*
200	.66
260	.50
300	.44

*This probability represents the proportion of vehicles that will hit illumination units given that their maximum lateral encroachment distance equals or exceeds the lateral distance that illumination units are from the near edge of the traffic lane. It is assumed that the point of departure from the roadway is random, i.e., is not related to the location of lighting units.

TABLE 6

PROBABILITY THAT AN ENCROACHING VEHICLE WILL HIT AN ILLUMINATION UNIT, BY LATERAL DISTANCE AND SPACING OF ILLUMINATION UNITS

Unit Spacing (feet)	Distance of Units From Edge of Traffic Lane (feet)			
	10	20	25	30
200	.594	.429	.297	.165
260	.450	.325	.225	.125
300	.396	.286	.198	.110

number of lighting units that will be hit per mile per year on a roadway with units placed in the median, with a two-way average daily traffic of 5,000 vehicles. For units placed on only one side ("house side") of the roadway, the values in Table 6 apply to a roadway with a two-way average daily traffic of 10,000 vehicles. Since accident rates are assumed to change in direct proportion to changes in traffic, accident rates can be calculated for any average daily traffic. For example, with median placement of lighting units and 300-foot spacings, and with units 30 feet from the through pavement edge (i. e., median and inside shoulders total 60 feet), with a two-way average daily traffic of 30,000 vehicles, the expected number of accidents per mile per year would be 6 times (6 encroachments per mile per year) the table value of 0.110, or 0.66.

The previous discussion of accident rates has assumed that the illumination units were exposed, or unprotected, and thus could be hit by motor vehicles. In some situations, however, this is not the case. Two situations in which units are not exposed are where the units are placed in a rigid median barrier and where the units are placed behind a bridge guardrail. In such cases, the accident rate with the lighting units will be considerably less than when fully exposed.

COST INFORMATION

TABLE 7

COST PER ILLUMINATION UNIT BY POLE HEIGHT, NUMBER OF ARMS, AND ARM LENGTH

Number of Arms and Arm Length	Initial Cost Per Unit by Mounting Height and Wattage	
	40-foot 400-watt	50-foot 1000 watt
Single Arm		
12-foot	$500	$625
15-foot	525	650
Double Arm		
12-foot	575	725
15-foot	625	775

NOTE: Cost includes foundation and installation cost but does not include cost of duct cable, conduit, or service poles. Costs are for galvanized steel poles on steel transformer bases or aluminum transformer bases.

and on the Dallas-Fort Worth Turnpike. Complete information was not given on all accidents; that which was given is shown in Table 8. The average costs, based on all available information, are given in Table 9 for four types of pole-base combinations. The average vehicle and lighting installation damage costs are based on the estimates in the accident reports. (The average injury costs shown in Table 9 are based on information given in Tables 10 and 11.) Table 10 shows the numbers and types of injuries for the four types of pole-base combinations. This information on types of injuries was taken from the accident reports. The accident reports did not estimate any injury cost. The National Safety Council[3] has given, however, values of cost for Texas for the three types of injuries--A, B, and C--which are given on accident reports, and these costs are shown in Table 11. The information on numbers of accidents by type, shown in Table 10, is used with the accident cost information in Table 11 to get "weighted" average accident injury costs which are shown in Table 9.

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TABLE 8

NUMBER OF TOTAL ACCIDENTS AND NUMBER OF ACCIDENTS FOR WHICH INFORMATION ON COSTS IS COMPLETE, BY TYPE OF COST

Type of Pole	Type of Base	Total Number of Accidents	Number of Accidents With Complete Information of This Type:			
			Injury Types (for Cost)	Vehicle Damage Cost	Lighting Installation Damage Cost	All Three Costs
Aluminum	Aluminum Transformer	58	58	48	55	47
Steel	Aluminum Transformer	19	19	15	15	13
Steel	Steel Transformer	37	37	27	31	25
Steel	Steel Shoe	35	35	35	35	35

TABLE 9

AVERAGE ACCIDENT COSTS BY TYPE OF COST FOR DIFFERENT BASE AND POLE TYPES

Type of Pole	Type of Base	Average Injury Cost	Average Vehicle Damage Cost	Average Lighting Installation Damage Cost	Average Total Accident Cost
Aluminum	Aluminum Transformer	$174 (58)	$381 (48)	$221 (47)	$776
Steel	Aluminum Transformer	272 (19)	400 (15)	313 (13)	985
Steel	Steel Transformer	603 (37)	501 (31)	231 (25)	1335
Steel	Steel Shoe	823 (35)	541 (35)	103 (35)	1467

Note: Numbers in parentheses are the numbers of accidents used in that particular average.

TABLE 10

NUMBER OF ACCIDENTS AND NUMBER OF INJURIES BY TYPE OF INJURY, FOR FOUR POLE-BASE COMBINATIONS

Type of Pole	Type of Pole	Number of Accidents	Number of Injuries of this type		
			A	B	C
Aluminum	Aluminum Transformer	58	2	4	7
Steel	Aluminum Transformer	19	3	0	2
Steel	Steel Transformer	37	12	3	5
Steel	Steel Shoe	35	14	9	0

TABLE 11

ESTIMATED AVERAGE INJURY COSTS FOR TEXAS FOR THE YEAR 1967

Type of Injury	Cost
A	$1,415
B	1,000
C	465

NOTE: The injury costs include doctor, hospital, and medical expenses and the cost of work time lost due to injury but do not include any cost for suffering and pain.

A type "A" injury is one that entails a visible injury, such as a distorted member or bleeding, or results in the injured person being carried from the accident scene. A type "B" injury is one that is visible and includes bruises, abrasions, swelling, and limping. A type "C" injury is one that is not visible but for which the injured person complains of pain or momentary unconsciousness.

COMPARISONS OF ALTERNATIVES

Comparisons of Alternatives

In making comparisons of the five illumination designs, those which give the same level of effectiveness are compared on a cost basis. The present value of costs for analysis periods of twenty and forty years are calculated using an interest rate of .05 per year. No salvage values are used, since it is uncertain what they would be. In calculating costs two sets of maintenance costs are used; "low" maintenance costs per luminaire per year are $25 for 400-watt luminaires and $50 for 1000-watt luminaires, whereas "high" maintenance costs are $40 for 400-watt luminaires and $70 for 1000-watt luminaires. Two sets of accident costs are also used, one set based on an average daily traffic of 10,000 vehicles, and the other of 30,000 vehicles.

Table 12 presents initial costs per mile of roadway for the five designs with 12-foot and 15-foot arms. These initial costs include those of the actual illumination units and of duct cable, conduit, and service poles. On an initial cost basis, design B is least expensive, followed by C, E, A, and D, in the order given. Design E is more expensive than design B because units are staggered and are placed on both sides of the roadway, resulting in extra cost for duct cable and conduit. Designs A and C tend to have higher initial costs because each unit has two arms and two luminaires. Design D requires duct cable and conduit for both sides, since it, like design E, is staggered. It also has a smaller spacing distance than the other 50-foot mounting height designs.

Tables 13 and 14 include "low" and "high" maintenance costs per mile for analysis periods of twenty and forty years. The maintenance costs for alternatives B and E are the same in all respects and are the least expensive. Maintenance costs for design D are about fifteen or twenty percent higher than for B and E because of more units per mile. Design A has the most luminaires per mile, which is only partially offset by their being 400-watt (whereas all other designs have 1000-watt). As was the case with initial costs, designs A and C have relatively high maintenance costs because the units have two luminaires per pole. Maintenance costs per mile for design C are exactly double those for designs B and E, since the wattage and spacings are the same. Design A, however, has two luminaires per unit, whereas designs B and E have only one.

Tables 15 and 16 give accident costs for analysis periods of, respectively, twenty and forty years. These accident costs per mile are based on the accident rate information given in Table 6, and costs per accident, for steel poles mounted on aluminum transformer bases, of $985, from Table 9. The accident costs are shown for different daily traffic volumes and different distances from the edge of the pavement to the illumination units. For a given average daily traffic and distance from the pavement edge, designs B and E have the lowest accident costs; design D has accident costs slightly higher than B or E because of the closer spacing of units. Accident costs for design C are double those for designs B and E, assuming all are placed the same distance from the pavement. The reason for this is due to

TABLE 12

INITIAL COST, BY TYPE OF ILLUMINATION DESIGNS, PER MILE OF ROADWAY, WITH 12-FOOT AND 15-FOOT ARMS

Illumination Design	Arm Length (feet)	Number of Illumination Units Per Mile	Initial Costs Per Mile		
			Illumination Units	Other*	Total
A(M-40-200)	12	26.4	$15,180	$3,400	$18,580
A(M-40-200)	15	26.4	16,500	3,400	19,900
B(0-50-300)	12	17.6	11,000	3,400	14,400
B(0-50-300)	15	17.6	11,440	3,400	14,840
C(M-50-300)	12	17.6	12,760	3,400	16,160
C(M-50-300)	15	17.6	13,640	3,400	17,040
D(S-50-260)	12	20.31	12,694	6,500	19,194
D(S-50-260)	15	20.31	13,201	6,500	19,702
E(S-50-300)	12	17.6	11,000	6,500	17,500
E(S-50-300)	15	17.6	11,440	6,500	17,940

*Includes costs of duct cable, conduit, and service pole.

TABLE 13

LOW MAINTENANCE COSTS FOR DIFFERENT ILLUMINATION DESIGNS, FOR TWENTY-YEAR AND FORTY-YEAR ANALYSIS PERIODS

Illumination Design	Number of Luminaires Per Mile	Maintenance Cost Per Mile Per Year	Present Value of Maintenance Cost Per Mile by Length of Analysis Period	
			20 years	40 years
A(M-40-200)	52.80	$1,320.00	$16,450	$22,650
B(0-50-300)	17.60	880.00	10,967	15,100
C(M-50-300)	35.20	1,760.00	21,933	30,200
D(S-50-260)	20.31	1,015.50	12,655	17,425
E(S-50-300)	17.60	880.00	10,967	15,100

TABLE 14

HIGH MAINTENANCE COSTS FOR DIFFERENT ILLUMINATION DESIGNS, FOR TWENTY-YEAR AND FORTY-YEAR ANALYSIS PERIODS

Illumination Design	Number of Luminaires Per Mile	Maintenance Cost Per Mile Per Year	Present Value of Maintenance Cost Per Mile by Length of Analysis Period	
			20 years	40 years
A(M-40-200)	52.80	$2,112.00	$26,320	$36,240
B(0-50-300)	17.60	1,232.00	15,353	21,140
C(M-50-300)	35.20	2,464.00	30,706	42,280
D(S-50-260)	20.31	1,491.70	18,590	25,596
E(S-50-300)	17.60	1,232.00	15,353	21,140

NOTE: The "high" maintenance cost per luminaire per year is $40 for Design A which is 400-watt and is $70 for the other designs which are 1000-watt.

TABLE 15

PRESENT VALUE OF ACCIDENT COSTS PER MILE FOR DIFFERENT ILLUMINATION DESIGNS, BY AVERAGE DAILY TRAFFIC AND DISTANCE OF ILLUMINATION UNITS FROM TRAFFIC LANE, FOR AN ANALYSIS PERIOD OF TWENTY YEARS

Illumination Design	Accident Cost by ADT and Distance of Units from Traffic Lane							
	ADT = 10,000				ADT = 30,000			
	10'	20'	25'	30'	10'	20'	25'	30'
A(M-40-200)	$14,485	$10,532	$7,291	$4,051	$43,454	$31.596	$21,874	$12,152
B(0-50-300)	4,861	3,511	2,430	1,346	14,583	10,532	7,290	4,050
C(M-50-300)	9,722	7,021	4,861	2,701	29,166	21,064	14,583	8,102
D(S-50-260)	5,524	3,989	2,767	1,533	16,571	11,968	8,300	4,598
E(S-50-300)	4,861	3,511	2,430	1,346	14,583	10,532	7,290	4,050

TABLE 16

PRESENT VALUE OF ACCIDENT COSTS PER MILE FOR DIFFERENT ILLUMINATION DESIGNS, BY AVERAGE DAILY TRAFFIC AND DISTANCE OF ILLUMINATION UNITS FROM THE EDGE OF TRAFFIC LANE, FOR AN ANALYSIS PERIOD OF FORTY YEARS

Illumination Design	Accident Cost by ADT and Distance of Units from Traffic Lane							
	ADT = 10,000				ADT = 30,000			
	10'	20'	25'	30'	10'	20'	25'	30'
A(M-40-200)	$19,939	$14,499	$10.038	$5,577	$59,833	$43,498	$30,114	$16,730
B(0-50-300)	6,632	4,839	3,346	1,853	20,076	14,499	10,038	5,577
C(M-50-300)	13,384	9,661	6,692	3,724	40,152	28,999	20,076	11,153
D(S-50-260)	7,601	5,491	3,809	2,111	22,821	16,473	11,411	6,332
E(S-50-300)	6,692	4,839	3,346	1,853	20,076	14,499	10,038	5,577

the fact that an equal number of vehicles run off the left and right sides of the roadway; thus, units in the median will be hit by vehicles from both directions, whereas units on the "house side" will only be hit half as many times for the same spacing. Accident costs for design A are the highest because of the relatively short spacing and because of the median placement.

Table 17 gives the present value of the sum of initial and maintenance costs for the designs but does not include accident costs. Tables 18, 19, 20, and 21 are the same as Table 17, except that they also include accident costs for units placed different distances from the edge of the roadway. Accident costs are lower the farther the distance they are located off the roadway.

In the first section of the report, three levels of effectiveness are defined. The highest level of effectiveness is Level III, which gives an average illumination of 1.25 horizontal foot-candles, followed by Level II, with an average illumination of 1.00 horizontal foot-candles, and Level I, with 0.75 horizontal foot-candles. In Table 3, the alternatives, or designs, which met these effectiveness criteria on roadways with different numbers of lanes are given. The following discussion compares, on a cost basis, those designs which give a particular level of effectiveness on a specific roadway.

For four-lane roadways, design B meets criterion III, and both designs A and B meet criteria II and I. From the information in Tables 17 through 21, it can be seen that design B is always less expensive than design A; therefore, design B is the most acceptable. If, however,

TABLE 17

PRESENT VALUE OF INITIAL AND MAINTENANCE COSTS, PER MILE OF ROADWAY, FOR DIFFERENT ILLUMINATION DESIGNS, BY LENGTH OF ARMS, LEVEL OF MAINTENANCE COSTS, AND LENGTH OF THE ANALYSIS PERIOD

Illumination Design	12-ft. Arm(s)				15-ft. Arm(s)			
	Low MC		High MC		Low MC		High MC	
	M=20	M=40	M=20	M=40	M=20	M=40	M=20	M=40
A(M-40-200)	$35,030	$41,230	$44,900	$54,820	$36,350	$42,550	$46,200	$56,140
B(O-50-300)	25,367	29,500	29,753	35,540	25,807	29,940	30,193	35,980
C(M-50-300)	38,093	46,360	46,866	58,440	38,973	47,240	47,746	59,320
D(S-50-260)	31,849	36,619	37,784	44,790	32,357	37,127	38,292	45,298
E(S-50-300)	28,467	32,600	32,853	38,640	28,907	33,040	33,293	39,080

NOTE: MC signifies maintenance cost; M is the length, in years, of the analysis period. In calculating present values, an interest rate of .05 per year is used.

TABLE 18

PRESENT VALUE OF INITIAL, MAINTENANCE, AND ACCIDENT COSTS, PER MILE OF ROADWAY, FOR DIFFERENT ILLUMINATION DESIGNS, BY AMOUNT OF AVERAGE DAILY TRAFFIC, LEVEL OF MAINTENANCE COST, AND LENGTH OF ANALYSIS PERIOD FOR UNITS WITH 12-FOOT ARMS, PLACED TEN FEET FROM THE TRAFFIC LANE

Illumination Design	ADT = 10,000				ADT = 30,000			
	Low MC		High MC		Low MC		High MC	
	M=20	M=40	M=20	M=40	M=20	M=40	M=20	M=40
A(M-40-200)	$49,515	$61,169	$59,385	$74,759	$78,484	$101,063	$88,354	$114,653
B(0-50-300)	30,228	36,192	34,614	42,232	39,950	49,576	44,336	55,616
C(M-50-300)	47,815	59,744	56,588	71,824	67,259	86,512	76,032	98,592
D(S-50-260)	37,373	44,220	43,308	52,391	48,420	59,440	54,355	67,611
E(S-50-300)	33,328	39,292	37,714	45,332	43,050	52,676	47,436	58,716

NOTE: MC signifies maintenance cost; M is the length, in years, of the analysis period. In calculating present values, an interest rate of .05 per year is used.

TABLE 19

PRESENT VALUE OF INITIAL, MAINTENANCE, AND ACCIDENT COSTS, PER MILE OF ROADWAY, FOR DIFFERENT ILLUMINATION DESIGNS, BY AMOUNT OF AVERAGE DAILY TRAFFIC, LEVEL OF MAINTENANCE COST, AND LENGTH OF ANALYSIS PERIOD FOR UNITS WITH 15-FOOT ARMS, PLACED TWENTY FEET FROM THE TRAFFIC LANE

Illumination Design	ADT = 10,000				ADT = 30,000			
	Low MC		High MC		Low MC		High MC	
	M=20	M=40	M=20	M=40	M=20	M=40	M=20	M=40
A(M-40-200)	$46,882	$57,049	$56,752	$70,639	$67,946	$86,048	$77,816	$99,638
B(0-50-300)	29,318	34,779	33,704	40,819	36,339	44,439	40,725	50,479
C(M-50-300)	45,994	56,901	54,767	68,981	60,037	76,239	68,810	88,319
D(S-50-260)	36,346	42,618	42,281	50,789	44,325	53,600	50,260	61,771
E(S-50-300)	32,418	37,879	36,804	43,919	39,439	47,539	43,825	53,579

TABLE 20

PRESENT VALUE OF INITIAL, MAINTENANCE, AND ACCIDENT COSTS, PER MILE OF ROADWAY, FOR DIFFERENT ILLUMINATION DESIGNS, BY AMOUNT OF AVERAGE DAILY TRAFFIC, LEVEL OF MAINTENANCE COST, AND LENGTH OF ANALYSIS PERIOD FOR UNITS WITH 15-FOOT ARMS, PLACED TWENTY-FIVE FEET FROM THE TRAFFIC LANE

Illumination Design	ADT = 10,000				ADT = 30,000			
	Low MC		High MC		Low MC		High MC	
	M=20	M=40	M=20	M=40	M=20	M=40	M=20	M=40
A(M-40-200)	$43,641	$52,588	$53,511	$66,178	$58,224	$72,664	$68,094	$86,254
B(O-50-300)	28,237	33,286	32,623	39,326	33,097	39,978	37,483	46,018
C(M-50-300)	43,834	53,932	52,607	66,012	53,556	67,316	62,329	79,396
D(S-50-260)	35,124	40,936	41,059	49,107	40,657	48,538	46,592	56,709
E(S-50-300)	31,337	36,386	35,723	42,426	36,197	43,078	40,583	49,118

NOTE: MC signifies maintenance cost; M is the length, in years, of the analysis period. In calculating present values, an interest rate of .05 per year is used.

TABLE 21

PRESENT VALUE OF INITIAL, MAINTENANCE, AND ACCIDENT COSTS, PER MILE OF ROADWAY, FOR DIFFERENT ILLUMINATION DESIGNS, BY AMOUNT OF AVERAGE DAILY TRAFFIC, LEVEL OF MAINTENANCE COST, AND LENGTH OF ANALYSIS PERIOD FOR UNITS WITH 15-FOOT ARMS, PLACED THIRTY FEET FROM THE TRAFFIC LANE

Illumination Design	ADT = 10,000				ADT = 30,000			
	Low MC		High MC		Low MC		High MC	
	M=20	M=40	M=20	M=40	M=20	M=40	M=20	M=40
A(M-40-200)	$40,401	$48,127	$50,271	$61,717	$48,502	$59,280	$58,372	$72,870
B(O-50-300)	27,153	31,793	31,539	37,833	29,857	35,517	34,243	41,557
C(M-50-300)	41,674	50,964	50,447	63,044	47,075	58,393	55,848	70,473
D(S-50-260)	33,890	39,238	39,825	47,409	36,955	43,459	42,890	51,630
E(S-50-300)	30,253	34,893	34,639	40,933	32,957	38,617	37,343	44,657

NOTE: MC signifies maintenance cost; M is the length, in years, of the analysis period. In calculating present values, in interest rate of .05 per year is used.

the illumination units for design A are to be placed in a rigid median barrier, and the units for design B are to be exposed on the side of the roadway, then for a relatively long analysis period and/or relatively high traffic volume, design A is preferable. For example, design A in a rigid median barrier is less expensive than design B with exposed units placed ten feet from the edge of the pavement, for an average daily traffic of 30,000 vehicles. This is the case if the analysis period is forty years, or if the analysis period is twenty years, and low maintenance costs are assumed (See Tables 17 and 18).

For six-lane roadways designs C and D meet the highest effectiveness criterion, Level III. Design D is less expensive than design C, except for situations wherein, under design C, units are to be placed in a rigid median barrier and relatively high average daily traffic is expected. For the lower effectiveness criteria at Levels II and I, designs A, B, and E are also feasible, and design B is the least costly of the alternatives.

For eight-lane roadways design C is the only design which meets the effectiveness criteria for Level III. For Levels II and I, design D also meets the effectiveness criteria and is preferable to design C on a cost basis, except for some situations where, under design C, units are placed in a rigid median barrier. In this case, accident costs for design C are zero.

For ten-lane roadways, design C is the only design which meets the effectiveness criteria and, therefore, is the only feasible alternative for all three levels of effectiveness.

If it is anticipated that additional traffic lanes will be added to a roadway, this should be considered in the analysis of alternatives. For example, if design D is used on a six-lane roadway, it gives Level III, but if this facility later has two lanes added, design D would then give only Level II; if four lanes are added, design D would not even meet the criteria for Level I. Thus, it can be seen that the flexibility of the design should be considered when making comparisons.

All of the above comparisons assume that steel poles on aluminum transformer bases are used. If the illumination units are exposed, the accident costs with steel poles and aluminum transformer bases are about 36 percent, or $350 per accident, less expensive than with steel poles and steel transformer bases and are about 49 percent, or $482 per accident, less expensive than with steel poles and steel shoe bases. Since the aluminum transformer base costs about the same as the steel transformer base, it is clearly preferable for units which are exposed. Any break-away base, such as a slip base or the aluminum transformer base, costs only about $40 more per base than a shoe base. This gives an extra cost of $704 per mile for 300-foot spacings. With an ADT of 10,000 vehicles, the present value of savings in accident cost for a twenty-year analysis period, assuming units are placed ten feet from the pavement, of using transformer bases instead of steel shoe bases, is about $7,000. Thus, in this particular situation with a relatively low average daily traffic of 10,000 vehicles, the benefit-cost ratio of using aluminum transformer bases is about ten to one. Another report of a Texas Transportation Institute study[4] includes a further discussion of cost-effectiveness analysis of break-away bases for lighting installations. There also are indications that aluminum poles on aluminum transformer bases give lower costs per accident. For exposed illumination units, therefore, the extra cost of aluminum poles may be justified by accident cost savings. Due to excessive vibration, however, the aluminum poles have presented some problems at the higher mounting heights. Even at low mounting heights, if the illumination units are to be placed in a rigid median barrier or behind bridge guardrails thus lessening the incidence of accidents, steel poles are clearly less expensive than aluminum poles.

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