ECONOMIC AND ACCIDENT POTENTIAL ANALYSIS OF ROADWAY LIGHTING ALTERNATIVES

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The objective of this study was to investigate cost-effectiveness relationships for various roadway lighting design criteria and roadway geometry. Lighting design criteria (effectiveness), consisting of average illumination, average-to-minimum ratios of illumination, and maximum-to-minimum ratios of illumination, were applied to roadway geometry configurations of four, six, eight, and ten traffic lanes. Five illumination design alternatives were selected and compared on the basis of the design criteria for the various roadway configurations. Cost data used in the study included initial, maintenance, operational, and accident costs. Comparisons were made on a cost basis for those designs that gave a particular level of effectiveness for a specific roadway. Tables summarize the cost-effectiveness relationships.

• THE purpose of this study is to give highway administrators and lighting designers realistic guidelines for determining optimum roadway lighting installations by considering levels and uniformity of illumination, roadway geometry, and accidents involving vehicle collisions with lighting supports.

The method used in the study is to determine the least costly of several alternatives that give the same level of effectiveness under certain stipulated conditions. The study is limited to continuous roadway lighting and also is limited in that only mounting heights of 40 and 50 ft are considered. The costs used are derived from Texas experience and, therefore, are limited in that sense. It is felt, however, that the general conclusions of the study are valid for areas other than Texas.

Previous work by Cassel and Medville (1) has provided information for making cost estimates prior to construction of a lighting system. It was reported that, to reduce system costs, fewer poles per mile should be used, and the number of poles could be reduced by using more efficient light sources, larger lamps, and higher mounting heights. Thompson and Fansler (2) concluded that lighting designs with mounting heights of 40 to 50 ft provide more economical and effective lighting than do those requiring the usual 30-ft mounting height. They also concluded that higher mounting heights normally provide for safer and more aesthetic lighting designs.

Although these studies and others have provided most of the information necessary to optimize cost-effectiveness, they have omitted explicit consideration of vehicle collisions with luminaire supports. This report attempts to give guidelines for determining optimum roadway lighting installations by considering levels and uniformity of illumination, roadway geometry, and accidents involving vehicle collisions with lighting supports.

OBJECTIVE

The objective of the research presented in this report was to investigate and report cost-effectiveness relationships for various roadway lighting design criteria and

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roadway geometry. Specifically, the objective included consideration of the following:

1. Design criteria
   a. Average illumination
   b. Average-to-minimum ratios of illumination
   c. Maximum-to-minimum ratios of illumination
2. Roadway geometry
   a. Four traffic lanes (total, both directions)
   b. Six traffic lanes (total, both directions)
   c. Eight traffic lanes (total, both directions)
   d. Ten traffic lanes (total, both directions)

EFFECTIVENESS CRITERIA AND ALTERNATIVES

Three effectiveness measures were used in selecting feasible alternatives: (a) a uniformity ratio of average illumination to minimum illumination of not greater than 3 to 1; (b) a uniformity ratio of maximum illumination to minimum illumination of not greater than 6 to 1; (c) three different levels of average illumination—level III, 1.25 horizontal footcandles, level II, 1.00 horizontal footcandle, and level I, 0.75 horizontal footcandle. There are, then, three levels of effectiveness or three design criteria, as summarized in Table 1.

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

Table 3 gives the illumination alternatives that 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.

ACCIDENT RATE PREDICTIONS

This section presents a method of predicting the number of vehicles that might be expected to collide with illumination units. The number of collisions is 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 that will hit light supports per mile of roadway per year, it is necessary to have estimates of (a) the number of vehicles that run off the road (out of the prescribed traffic lanes) per mile per year, (b) the paths of vehicles after they run off the road, and (c) the location of light supports with respect to the prescribed travel lanes.

TABLE 1

LEVELS OF EFFECTIVENESS DESIGN CRITERIA

Effectiveness Measure	Design Criteria		
	I	II	III
Average illumination (footcandles)	0.75	1.00	1.25
Average-to-minimum uniformity	3 to 1	3 to 1	3 to 1
Maximum-to-minimum uniformity	6 to 1	6 to 1	6 to 1

TABLE 2

ILLUMINATION ALTERNATIVES

Letter Used to Designate Alternative[a]	Unit Placement	Luminaire Wattage	Mounting Height (ft)	Unit Spacing (ft)
A (M-40-200)	Median	400	40	200
B (O-50-300)	One side	1,000	50	300
C (M-50-300)	Median	1,000	50	300
D (S-50-260)	Staggered	1,000	50	260
E (S-50-300)	Staggered	1,000	50	300

[a]The letters and numbers in parentheses refer to placement, mounting height in feet, and spacing of units in feet; M refers to units placed in the median; O refers to units placed on one side of the roadway; and S refers to units that are staggered, alternating on opposite sides of the roadway. Alternatives A and C with median placement have double arms and two luminaires. The other alternatives have single arms and one luminaire.

TABLE 3

ILLUMINATION ALTERNATIVES THAT FIT DIFFERENT DESIGN CRITERIA

Number of Traffic Lanes	Alternatives Fitting Criteria[a]		
	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

[a]For a description of criteria I, II, and III, see Table 1. For a description of alternatives A, B, C, D, and E, see Table 2.

Hutchinson and Kennedy (3) give information on median "encroachment" rates and vehicle paths. A median encroachment is defined by them as the travel of a 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 daily traffic. Their study covered divided highways without lighting in rural areas. Their encroachment rates are probably higher than the rates that should be used in this study for predicting lighting installation accidents for at least three reasons:

1. Some of their encroachments were probably intentional and also under control to such an extent that the driver could avoid hitting a lighting installation.
2. The roadways considered in this report will all be lighted, and 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 this 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 nonmedian (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 nonmedian encroachments occur in each direction. Thus, for nonmedian 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 nonmedian encroachment. For example, in the study of 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 probably vary for different roads because of differences in pavement types, road geometrics, weather, traffic composition, traffic speeds, and other driver, vehicle, road, or environmental conditions. Thus, the assumptions regarding encroachment rates may not be valid for a particular road. 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 road, it should be the side opposite the vehicles traveling in the direction of the afternoon sun.

The proportion of encroaching vehicles that actually hit illumination units, assuming the units are "unprotected," depends on the paths of encroaching vehicles and the placement of light poles. Hutchinson and Kennedy gave information on the paths of encroaching vehicles. 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 ft and a standard deviation of 11 ft for maximum lateral distances of less than 40 ft. Table 4 is based on this information. It indicates, for example, that about 90 percent of all encroaching vehicles would travel a lateral distance of at least 10 ft. Only 25 percent would travel a maximum lateral distance of at least 30 ft from the edge of the pavement.

TABLE 4

PROBABILITY THAT ENCROACHING VEHICLE WILL EQUAL OR EXCEED CERTAIN LATERAL MOVEMENTS

Maximum Lateral Movement (ft)	Approximate Probability	Maximum Lateral Movement (ft)	Approximate Probability
10	0.90	25	0.45
20	0.65	30	0.25

The next problem that arises is whether a vehicle that encroaches a lateral distance sufficient to hit a lighting installation will in fact hit such an installation. In other words, if illumination units are placed, say, 20 ft from the edge of the pavement, it is clear that about 35 percent of the encroaching vehicles will not hit a unit because their maximum lateral movement is less than 20 ft. However, the concern should be for the 65 percent of the encroaching vehicles that 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 hit a unit 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, i.e., 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 enchroaching 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 ft (taken as an average of vehicle width and length). It is further assumed that all vehicles leave the pavement at an 11-deg angle; this is the average encroachment angle found by Hutchinson and Kennedy in their study. By using 12.5 ft as the width of the vehicle path and an 11-deg encroachment angle, a distance of 131.3 ft for the numerator of the ratio is derived. The distance in the denominator of the ratio is the spacing between illumination units; for the alternatives considered in this analysis, this distance is 200, 260, or 300 ft.

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 ft 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 spacing of less than 131.3 ft, calculations would give a probability of greater than one; so, in terms of probabilities, this formulation does not hold for spacing of less than 131.3 ft. It does indicate, however, that for short spacings many vehicles will hit more than one unit if the first unit that they hit does not increase their deceleration sufficiently or redirect the vehicle. It is, of course, possible for one vehicle to hit two or more units with spacings greater than 131.3 ft. By using the simplified theory discussed previously, 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 ft from the near pavement and are spaced 200 ft apart, then the probability that a vehicle encroaching off the side of the pavement that is near the units will hit a unit is 0.594. This is obtained by multiplying the probability for a lateral distance of 10 ft (0.90) given in Table 4 by the conditional probability for spacings of 200 ft (0.66) given in Table 5.

Another way of interpreting the values in Table 6 is as the average number of lighting units that will be hit per mile per year on a road with units placed in the median and with a two-way average daily traffic of 5,000 vehicles. For units placed on only one side ("house side") of the road, the values in Table 6 apply to a road with a two-way average daily traffic of 10,000 vehicles. Because accident rates are assumed to change in direct proportion to changes in

TABLE 5

PROBABILITY THAT VEHICLE ENCROACHING BY SUFFICIENT DISTANCE WILL HIT ILLUMINATION UNIT

Illumination Unit Spacing (ft)	Conditional Probability[a]
200	0.66
260	0.50
300	0.44

[a]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 the lighting units.

TABLE 6

PROBABILITY THAT ENCROACHING VEHICLE WILL HIT AN ILLUMINATION UNIT

Unit Spacing (ft)	Probability of Hit by Distance of Units From Edge of Traffic Lane			
	10 ft	20 ft	25 ft	30 ft
200	0.594	0.429	0.297	0.165
260	0.450	0.325	0.225	0.125
300	0.396	0.286	0.198	0.110

traffic, accident rates can be calculated for any average daily traffic. For example, with median placement of lighting units and 300-ft spacings and with units 30 ft from the through pavement edge (i.e., median and inside shoulders are 60 ft wide), and 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 where units are not exposed are where the units are placed in a rigid median barrier and where the units are placed behind a bridge rail. In such cases, the accident rate with the lighting units should be negligible.

COST INFORMATION

The initial and maintenance costs computed for the five alternate designs are based on information furnished by manufacturers and information taken from bids on projects in Texas. The accident cost information is taken from Texas accident reports.

Table 7 gives per-unit initial costs for lighting installations. Costs are given for 40-ft and 50-ft mounting heights with 400-watt and 1,000-watt luminaires respectively. These costs are also given for single and double arms 12 and 15 ft long. These costs include foundation and installation costs but do not include costs for duct cable, conduit, or service poles. Also, the costs are for galvanized steel poles on steel or aluminum transformer bases. Steel poles on steel shoe bases would cost about $40 less per unit. Aluminum poles would cost $150 to $250 more per unit.

The cost of duct cable, conduit, and service poles is estimated at $3,400 per mile for installations placed in the median or on one side and at $6,500 per mile for installations that are staggered (alternating on each side) or opposite on two sides of the roadway.

Maintenance costs in Texas for power and luminaire replacement are estimated to range from $50 to $70 per year per luminaire for 1,000-watt luminaires and from $25 to $40 per year per luminaire for 400-watt luminaires.

Accident costs for collisions of vehicles with lighting installations are taken from a report by Lazenby (4) and from the accident records collected by him. The accident information covers accidents with lighting installations in Beaumont, Dallas, Fort Worth, Houston, and San Antonio and on the Dallas-Fort Worth Turnpike. Complete information was not given on all accidents; the amount of information available is given 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 damage costs and the average lighting installation damage costs are based on the estimates in the accident reports. The average injury costs given in Table 9 are based on information given in Tables 10 and 11. Table 10 gives 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. 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 of which the injured person complains of pain or momentary unconsciousness.

The accident reports did not estimate injury cost. The National Safety Council has, however, estimated values for the three types of injuries (A, B, and C) that are given on accident reports, and these costs are given in Table 11. The numbers of accidents by type given in Table 10 are used with the ac-

TABLE 7

COST PER ILLUMINATION UNIT

Number and Length of Arms	Initial Cost ($) Per Unit by Mounting Height and Wattage	
	40-ft, 400-watt	50-ft, 1,000-watt
Single arm		
12-ft	500	625
15-ft	525	650
Double arm		
12-ft	575	725
15-ft	625	775

TABLE 8

TOTAL NUMBER OF ACCIDENTS AND NUMBER OF ACCIDENTS FOR WHICH COMPLETE COST INFORMATION IS AVAILABLE

Type of Pole	Type of Base	Total Number of Accidents	Number of Accidents With Complete Cost Information			
			Injury Types	Vehicle Damage	Lighting Installation Damage	All Three
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

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)	1,335
Steel	Steel shoe	823 (35)	541 (35)	103 (35)	1,467

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

TABLE 10

NUMBER OF ACCIDENTS AND NUMBER OF INJURIES

Type of Pole	Type of Base	Number of Accidents	Number of Injuries		
			Type A	Type B	Type 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

cident cost information in Table 11 to derive the "weighted" average accident injury costs given in Table 9. The injury costs include doctor, hospital, and medical expenses and the cost of work time lost due to injury. The costs do not include any indemnification for suffering and pain.

COMPARISONS OF ALTERNATIVES

In making comparisons of the five illumination designs, those that meet the required effectiveness criteria are compared on a cost basis. The present value of costs for analysis periods of 20 and 40 years are calculated by using an interest rate of 5 percent per year. Two levels of maintenance costs, "low" and "high," are used. Also, two sets of accident costs are used, one set being based on an average two-way daily traffic of 10,000 vehicles and the other of 30,000 vehicles. In all of the calculations salvage values are assumed to be zero.

Table 12 gives initial costs per mile of roadway for the five designs with 12- and 15-ft arms. Table 13 gives low and high maintenance costs per mile for

TABLE 11

1967 ESTIMATED AVERAGE INJURY COSTS FOR TEXAS

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

analysis periods of 20 and 40 years. Tables 14 and 15 give accident costs for analysis periods of 20 and 40 years respectively. These accident costs are based on the accident rate information from Table 6, the cost per accident of $985 (for steel poles mounted on aluminum transformer bases from Table 9), and the previously discussed assumptions regarding encroachment rates. Table 16 gives the present value of the sum of initial and maintenance costs for the illumination designs but does not include accident costs.

Tables 17 through 20 are the same as Table 16 except that they include accident costs for units placed different distances from the edge of the roadway. As might

TABLE 12

INITIAL COSTS OF POLES

Illumination Design	Arm Length (ft)	Number of Illumination Units Per Mile	Initial Costs Per Mile		
			Illumination Units ($)	Other[a] ($)	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 (O-50-300)	12	17.6	11,000	3,400	14,400
B (O-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

[a]Includes costs of duct cable, conduit, and service pole.

TABLE 13

MAINTENANCE COSTS FOR DIFFERENT ILLUMINATION DESIGNS

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	
		Low ($)	High ($)	Low ($)	High ($)	Low ($)	High ($)
A (M-40-200)	52.80	1,320	2,112	16,450	26,320	22,650	36,240
B (O-50-300)	17.60	880	1,232	10,967	15,353	15,100	21,140
C (M-50-300)	35.20	1,760	2,464	21,933	30,706	30,200	42,280
D (S-50-260)	20.31	1,015	1,492	12,655	18,590	17,425	25,596
E (S-50-300)	17.60	880	1,232	10,967	15,353	15,100	21,140

TABLE 14

PRESENT VALUE OF ACCIDENT COSTS PER MILE FOR DIFFERENT ILLUMINATION DESIGNS, 20-YEAR PERIOD

Illumination Design	Accident Cost by ADT and Distance of Units From Traffic Lane							
	10,000 ADT				30,000 ADT			
	10 ft ($)	20 ft ($)	25 ft ($)	30 ft ($)	10 ft ($)	20 ft ($)	25 ft ($)	30 ft ($)
A (M-40-200)	14,485	10,532	7,291	4,051	43,454	31,596	21,874	12,152
B (O-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 15

PRESENT VALUE OF ACCIDENT COSTS PER MILE FOR DIFFERENT ILLUMINATION DESIGNS, 40-YEAR PERIOD

Illumination Design	Accident Cost by ADT and Distance of Units From Traffic Lane							
	10,000 ADT				30,000 ADT			
	10 ft ($)	20 ft ($)	25 ft ($)	30 ft ($)	10 ft ($)	20 ft ($)	25 ft ($)	30 ft ($)
A (M-40-200)	19,939	14,499	10,038	5,577	59,833	43,498	30,114	16,730
B (O-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

TABLE 16

PRESENT VALUE OF INITIAL AND MAINTENANCE COSTS PER MILE OF ROADWAY FOR DIFFERENT ILLUMINATION DESIGNS

Illumination Design	12-ft Arm(s)				15-ft Arm(s)			
	Low Maint. Cost		High Maint. Cost		Low Maint. Cost		High Maint. Cost	
	20 years ($)	40 years ($)	20 years ($)	40 years ($)	20 years ($)	40 years ($)	20 years ($)	40 years ($)
A (M-40-200)	35,030	41,230	44,900	54,820	36,350	42,550	46,220	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: Present values were calculated by using an interest rate of 5 percent per year.

TABLE 17

PRESENT VALUE OF INITIAL, MAINTENANCE, AND ACCIDENT COSTS PER MILE OF ROADWAY FOR UNITS WITH 12-FT ARMS PLACED 10 FT FROM TRAFFIC LANE

Illumination Design	10,000 ADT				30,000 ADT			
	Low Maint. Cost		High Maint. Cost		Low Maint. Cost		High Maint. Cost	
	20 years ($)	40 years ($)	20 years ($)	40 years ($)	20 years ($)	40 years ($)	20 years ($)	40 years ($)
A (M-40-200)	49,515	61,169	59,385	74,759	78,484	101,063	88,354	114,653
B (O-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: Present values were calculated by using an interest rate of 5 percent per year.

TABLE 18

PRESENT VALUE OF INITIAL, MAINTENANCE, AND ACCIDENT COSTS PER MILE OF ROADWAY FOR UNITS WITH 15-FT ARMS PLACED 20 FT FROM TRAFFIC LANE

Illumination Design	10,000 ADT				30,000 ADT			
	Low Maint. Cost		High Maint. Cost		Low Maint. Cost		High Maint. Cost	
	20 years ($)	40 years ($)	20 years ($)	40 years ($)	20 years ($)	40 years ($)	20 years ($)	40 years ($)
A (M-40-200)	46,882	57,049	56,752	70,639	67,946	86,048	77,816	99,638
B (O-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

Note: Present values were calculated by using an interest rate of 5 percent per year.

TABLE 19

PRESENT VALUE OF INITIAL, MAINTENANCE, AND ACCIDENT COSTS PER MILE OF ROADWAY FOR UNITS WITH 15-FT ARMS PLACED 25 FT FROM TRAFFIC LANE

Illumination Design	10,000 ADT				30,000 ADT			
	Low Maint. Cost		High Maint. Cost		Low Maint. Cost		High Maint. Cost	
	20 years	40 years	20 years	40 years	20 years	40 years	20 years	40 years
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: Present values were calculated by using an interest rate of 5 percent per year.

TABLE 20

PRESENT VALUE OF INITIAL, MAINTENANCE, AND ACCIDENT COSTS PER MILE OF ROADWAY FOR UNITS WITH 15-FT ARMS PLACED 30 FT FROM TRAFFIC LANE

Illumination Design	10,000 ADT				30,000 ADT			
	Low Maint. Cost		High Maint. Cost		Low Maint. Cost		High Maint. Cost	
	20 years	40 years	20 years	40 years	20 years	40 years	20 years	40 years
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: Present values were calculated by using an interest rate of 5 percent per year.

be expected, the accident costs are lower the farther the illumination units are located off the roadway.

In the first section of this report, three levels of effectiveness are defined. The highest of these levels is level III, with an average illumination of 1.25 horizontal footcandles, followed by level II with 1.00 horizontal footcandle and level I with 0.75 horizontal footcandle. In Table 3 the designs that meet these effectiveness criteria on roadways with different numbers of lanes are given. The following discussion compares, on the basis of the costs given in Tables 17 through 20, those designs that 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. In Tables 17 through 20, it is seen that design B is always less expensive than design A; therefore, under these conditions design B is preferred. If, however, 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 10 ft from the edge of the pavement for an average daily traffic of 30,000 vehicles, if the analysis period is 40 years or if the analysis period is 20 years and low maintenance costs are assumed (see Tables 16 and 17).

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, 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 that 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 that meets the effectiveness criteria and, therefore, is the only feasible alternative for each of the 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; however, 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.

TABLE 21

BENEFIT-COST RATIOS FOR USING ALUMINUM TRANSFORMER BASES

Illumination Design	Extra Initial Cost Per Mile Due to Using Breakaway Bases ($)	Present Value of 20-Year Accident Cost Savings Per Mile Due to Using Breakaway Bases[a] ($)	20-Year Benefit-Cost Ratio of Using Breakaway Bases
A (M-40-200)	1,056	21,408	20.3
B (O-50-300)	704	7,136	10.1
C (M-50-300)	704	14,272	20.3
D (S-50-260)	812	8,109	10.0
E (S-50-260)	704	7,136	10.1

[a]Assuming two-way average daily traffic of 30,000 vehicles, unprotected illumination units placed 10 ft from edge of pavement, 20-year analysis period, and an interest rate of 5 percent per year. The comparison assumes steel poles are used.

ECONOMICS OF BREAKAWAY BASES

The comparisons of alternatives that are made in the preceding section assume that steel poles on aluminum transformer bases are used. It was assumed that aluminum transformer bases were used because the accident costs with these breakaway bases are considerably less than with the nonbreakaway bases, i.e., shoe bases and steel transformer bases. [Bases, other than the aluminum transformer type, that have breakaway characteristics are slip and shear bases; additional information is given by Edwards et al. (5).] The accident costs with steel poles and aluminum transformer bases are about 36 percent, or $350 per accident, less expensive than costs with steel poles and steel transformer bases and are about 49 percent, or $482 per accident, less expensive than costs with steel poles and steel shoe bases. Because the aluminum transformer base costs about the same as the steel transformer base, it is clearly preferable for units that are exposed. Any breakaway base, such as a slip base or the aluminum transformer base, costs about $40 more per base than a shoe base. Table 21 gives some 20-year benefit-cost ratios for using breakaway bases when the illumination units are placed 10 ft from the pavement edge and the two-way average daily traffic is 30,000 vehicles. If units were placed 20 ft from the pavement edge, the benefit-cost ratios would be approximately 75 percent of the values given in Table 21.

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. Because of 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.

SUMMARY AND CONCLUSIONS

In this paper, several lighting designs were compared on a cost basis. These lighting designs met certain levels of effectiveness on roadways with different numbers of lanes. In general, the 50-ft mounting heights were preferred over the 40-ft; for a small number of traffic lanes, the higher mounting heights are less expensive, and for eight or more lanes, the 40-ft mounting heights do not meet the effectiveness criteria. It is emphasized, however, that only certain heights are compared, and the conclusions are limited to those heights. It is also pointed out that the accident prediction model is based on several simplifying assumptions; it does, however, give logical results in that it predicts a greater number of accidents for median placement, for closer spacings, and for closer placement to traffic lanes.

Thompson and Fansler (2) and Cassel and Medville (1) in their research showed why, on a cost basis (not including accident costs), higher mounting heights are preferred.

This research supports their conclusions; inclusion of accident costs only reinforces that conclusion.

This research also shows how breakaway bases give large benefit-cost ratios, whatever the illumination design, if illumination units are exposed.

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