COMPARISON OF ACCIDENTS AND ILLUMINATION

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This paper summarizes findings from a study of illumination and accidents in Syracuse, New York. The night-day ratios of the number of accidents and the accident costs were calculated for one year of accident data (1967) and related to the illumination of each study section. Streets with little or no illumination were found to have substantially higher (poorer) night-day accident ratios and accident cost ratios than the average for all streets in the same roadway functional classification and type of abutting land use. The type of street appeared to be more of a factor in accident-illumination relation than the type of abutting land use. The methodology developed during the project is felt to represent a major contribution to the techniques in making such studies.

•A STUDY of roadway lighting in Syracuse was completed in 1970. The purposes of the project were to determine the type, amount, and priority of roadway lighting needed to reduce nighttime vehicle and pedestrian accidents and to determine the economic impact on the city of upgrading street lighting to national standards. The work included classification of each street in the city according to illumination as specified by the Illuminating Engineering Society (1). The streets were classified as major, collector, or local.

In general, local streets in Syracuse have traffic volumes of less than 2,000 vehicles per day, collector streets have volumes of 2,000 to 5,000, and major streets have volumes of more than 5,000. However, the actual function that each street serves—as a true collector or as a basic part of the major through-street system—was considered to be of at least equal significance in the classification.

The study was limited to the major and collector routes, which total 105 miles. Developments abutting these streets were checked, and the land use was classified as downtown, intermediate, or outlying areas. The downtown category includes the CBD and also secondary or neighborhood business districts. The intermediate category includes areas having some commercial activity, public buildings (schools, hospitals, and libraries), places of public assembly (auditoriums, churches, and stadiums), shopping centers, industrial areas, and retail sections having levels of activity somewhat less than that associated with downtown or community business centers. Streets abutted by major apartment developments, college dormitories, and similar high-density residential areas were classed as intermediate, for they often generate significant nighttime pedestrian traffic. The outlying areas include those where abutting land use consists of industrial, park, single-family residential, or vacant areas where little nighttime pedestrian activity is experienced.

The streets were field-checked to determine existing lighting and roadway widths. Where width, route type, or abutting land characteristics changed, separate sections were designated. Sections were further subdivided where a change occurred in lighting such as fixture size, type, mounting height, or overhang. This resulted in a total of 329 sections available for analysis.

The average maintained illumination was calculated for each section, and the length was recorded. It would have been desirable to take extensive field measurements of actual illumination, but the power company was unable to perform these checks.

The accident information was taken from the police data processing file for 1967. A computer program was developed by the Syracuse University Research Corporation to assign accidents to each roadway section.

It was impossible to pinpoint the exact location of accidents from the cards. If an accident occurred at a given intersection, it might be recorded as having occurred on either street. If both streets were included in the study, half of the accident (and its cost) could be assigned to each street. However, if the route had been divided into sections, there might be 2 or more sections involved with the same single intersection accident. Furthermore, if the intersection involved a local street that was not under study, it was impossible to determine whether the accident actually had occurred in the cross street and whether it had been influenced by the illumination level on the major or collector route section being studied.

The complications involved in using the records were extensive, and the data were less firm than we would have desired. In future work, it would be preferable to work directly from individual accident reports and to code the data on mark-sensing cards. These could then be processed through a reproducer, and regular IBM cards could be automatically punched. In this way, more details of injury and vehicular involvement, kinds of objects struck, directions of traffic movement, and legs of intersections in which rear-end accidents occurred could be simply and directly recorded.

In the Syracuse study, the accidents and costs were assigned as follows:

1. When an accident occurred at an intersection and the cross street was not in the study (i.e., it was a local street), the total cost of the accident was assigned to the appropriate section of the major or collector street and 1 accident was recorded for that section;
2. When an accident occurred at an intersection and the cross street was in the study or one section ended and another started at that intersection, the cost was divided by the number of section ends and assigned accordingly; and
3. Fractional accidents were later raised to whole numbers.

Accident records were summarized for day and night for each study section. The accident cost was estimated for the different sections as a function of the number of vehicles damaged and the number of persons killed or injured in each accident. The costs assumed for various types of accidents were taken from the Washington cost study (2).

The number of accidents and costs for each section were grouped separately by type of route and type of abutting land use. Sections having identical characteristics were consolidated.

Table 1 gives a summary of the data. The total of 3,161 night accidents and 4,334 day accidents exceeds the actual number that occurred because fractional numbers were raised to whole numbers.

ANALYSIS

The ratio of night accidents to day accidents was employed for the basic comparisons. This night-day ratio should equalize differences of traffic speeds, traffic composition, traffic volumes (to the degree not already compensated by route classification), and other variables such as type of pavement and parking characteristics. The lowest ratio of night-day accidents or accident costs indicates the best night accident experience.

For each of the classes, the sections having an illumination level at or above the 1963 specifications (1) were tabulated as group A, and those sections having lower values were tabulated as group B. Table 2 gives the night-day ratios for groups A and B. With some exceptions, group A streets had higher (poorer) accident ratios. The principal exception was class 5; but this class had only 3 percent of the route mileage and 4 percent of the accidents, and therefore this ratio was not considered significant.

The trend in the night-day ratio of accident costs was generally similar but more pronounced than for the number of accidents. However, class 6 showed a better night performance for the streets with higher illumination levels.

DETERMINATION OF OPTIMUM ILLUMINATION

The findings given in Table 2 would be expected (a) if both high- and low-illumination levels produced more hazardous driving conditions (a U-curve) or (b), alternatively, if the number of accidents increased directly with successively increasing amounts of illumination. To check for either condition, we grouped the sections to common levels of horizontal footcandles (HFC) maintained. Ranges of 0 (unlighted) to 3.0 or greater HFC were used. Figures 1 through 3 show graphs for classes 1, 2, and 6. Figure 1 shows 2 apparent low points: The first one centers at 1.05 HFC and is produced by a total accident sample of 132, and the second one is at 1.95 HFC and is based on an accident sample of 118.

The plots of both raw and weighted data are similar. Some of the higher ratio conditions in the higher footcandle levels on the right side of the graph are associated with comparatively large numbers of accidents. It appears, however, that the accident sample in the center range of the graph was inadequate to produce a "bottom" to the curve. The optimum illumination level could be at either one of the low points or between them.

Figure 2 shows a bottom occurring between 1.65 and 1.95 HFC. Only 38 accidents were included in the sample at the lower illumination level; 107 accidents were included at the 1.95-HFC plot. Fairly large numbers of accidents were associated with data plots at both the lower and the higher footcandle levels. Furthermore, this street class has nearly twice as many accidents as class 1 and more than 4 times the mileage. Findings on illumination needs, therefore, are of more significance. These indicate that the optimum illumination for this class of street is about 1.8 HFC.

The data on collector streets were based on relatively small samples, and the points are scattered. Apparent low points of 0.75 HFC were found for class 4 and 1.05 HFC for class 5. Class 6 data are shown in Figure 3. Low points appeared at 1.05 HFC (involving only 34 accidents) and at 1.35 HFC (involving 95 accidents). The plot at 1.95 HFC involves only 8 accidents and should be disregarded.

Figure 4 shows a plot of all major and collector street data used in the study. If a common illumination level were to be specified for all these streets, the apparent low point of 1.95 HFC would indicate this to be a nominal figure. However, data plots from individual classes show that this would be an uneconomically high concentration of light for a number of conditions. Furthermore, this higher illumination level produced a poorer accident ratio for several of the classes.

The ratios and low-point data are given in Table 3. These show that illumination levels of 0.75 to 1.8 HFC appear to be appropriate for the major streets and that levels of 0.75 to 1.05 appear to be the most appropriate for the collector streets. Because of the scattered data between class 1 and class 2, these groups were combined. Also because of the small sample size in class 4 and class 5, all collector routes were combined into a single grouping.

The night-day ratios for these combinations are given in Table 4 for both the raw and weighted data. These were similar in most cases. The appropriate illumination level for classes 1 and 2 appears to be in the range of 1.65 to 1.95 HFC. (This combined plot is shown in Figure 5—310 accidents at 1.65 HFC and 225 accidents at 1.95 HFC.) The optimum illumination level should lie some place within this range, and the midpoint of these 2 groupings is 1.8 HFC.

For class 3, a level of 0.75 appears to be appropriate. For the collector routes, the midpoint of the range is 1.05.

The ratios have been checked for statistical significance. The student t-test was employed; findings for classes 1 and 2 are significant at the 99 percent confidence level, for class 3 at the 90 percent level, and for classes 4, 5, and 6 at the 95 percent level.

Data were also tabulated by street classifications. The scatter of data in the night-day accident ratios was much greater for the land use classifications, and the indication is that the area characteristic is less of a factor than street classification.

A plot of night-day accident cost ratios for the major streets was also made. The optimum points appeared in the area of 1.65 to 1.95 HFC and are thus consistent with the analysis based only on the number of accidents.

OPTIMUM ACCIDENT COST RATIOS

The ratio of night-day accident costs was found to be about 0.8 when the optimum value of 1.8 HFC is provided for classes 1 and 2. This average value prevailed when either the unweighted or the weighted cost figures were used.

Table 1. Summary of study data.

Street	Land Use		Sections		Accidents				Miles	
	Location	Class	Number	Percent	Night	Day	Total	Percent	Number	Percent
Major	Downtown	1	40	12	551	913	1,464	19	5.7	5
	Intermediate	2	68	21	1,099	1,424	2,523	34	23.0	22
	Outlying	3	69	21	679	807	1,486	20	31.5	30
Collector	Downtown	4	12	4	82	109	191	3	1.4	1
	Intermediate	5	17	5	110	189	299	4	3.0	3
	Outlying	6	123	37	640	892	1,532	20	40.7	39
Total			329	100	3,161	4,334	7,495	100	105.3	100

Table 2. IES specifications and night-day accident ratios.

Class	Specification (HFC)	Accident Ratio		Accident Cost Ratio	
		Group A	Group B	Group A	Group B
1	2.0	0.73	0.52	2.03	0.49
2	1.2	0.79	0.76	2.06	1.54
3	0.9	1.02	0.80	1.75	0.29
4	1.2	0.87	0.64	4.80	0.75
5	0.9	0.41	0.63	0.38	1.37
6	0.6	0.72	0.72	1.08	1.37

Figure 1. Relation between illumination level and accident experience for class 1 streets.

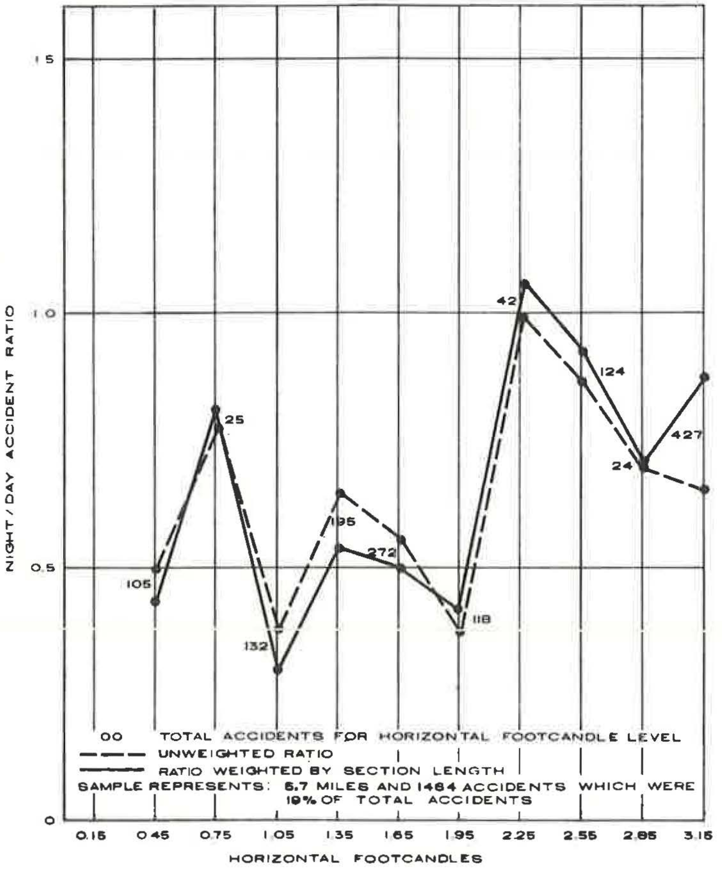

Figure 2. Relation between illumination level and accident experience for class 2 streets.

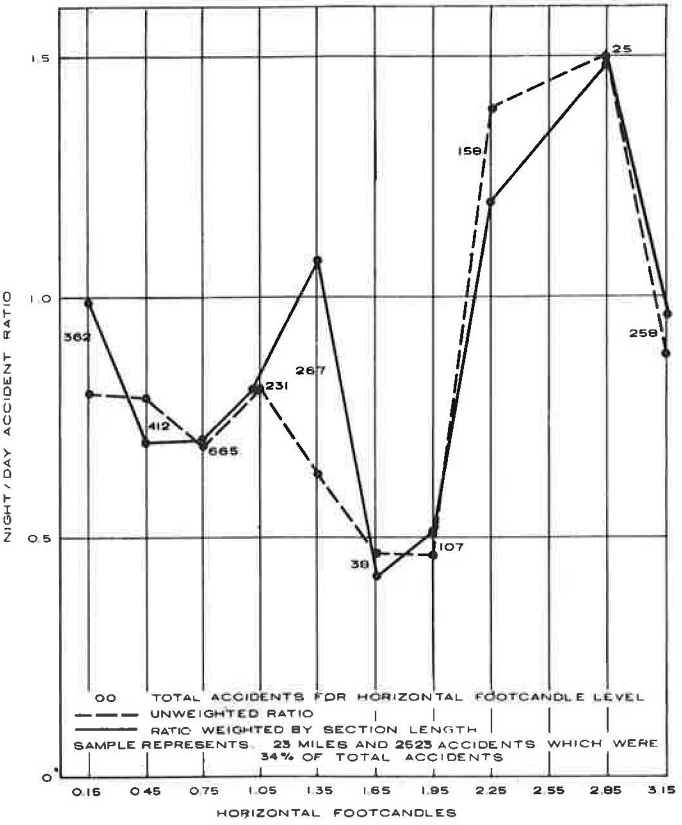

Figure 3. Relation between illumination level and accident experience for class 6 streets.

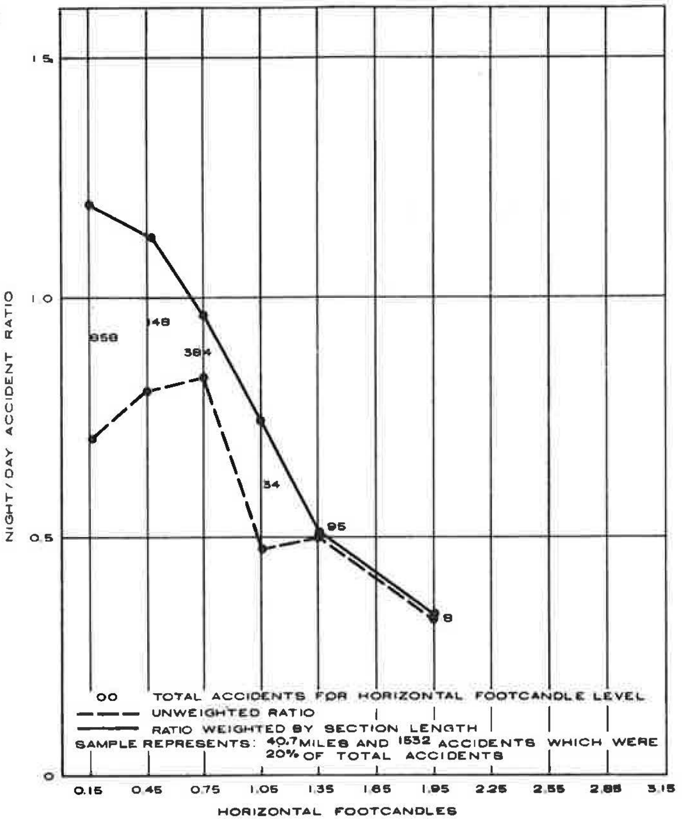

Figure 4. Relation between illumination level and accident experience for all street classes.

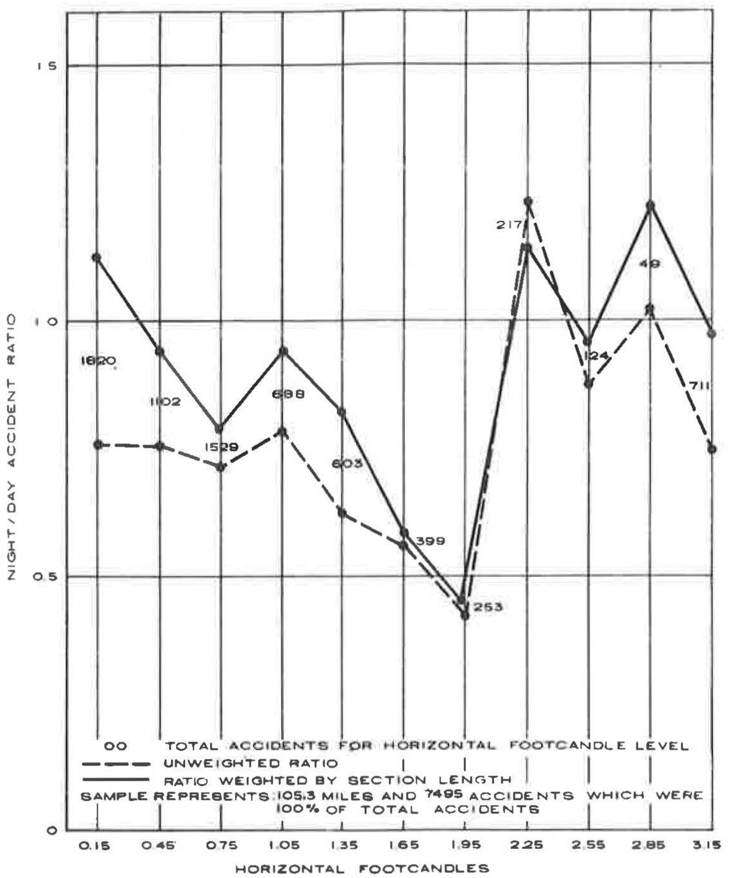

Table 3. Illumination levels that produce lowest night-day accident ratios.

Class	Accident Ratio	Illumination Level (HFC)	Specification (HFC)
1	0.38	1.05	2.0
2	0.46	1.8	1.2
3	0.62-0.54	0.75-1.6	0.9
4	0.36	0.75	1.2
5	0.36	1.05	0.9
6	0.47	1.05	0.6
Avg	0.42	1.95	

Table 4. Night-day accident ratios and optimum illumination levels.

Class	Data	Avg Accident Ratio	Low Accident Ratio	Optimum Illumination Level
1, 2	Raw[a]	0.71	0.42	1.95
	Weighted[b]	0.82	0.46	1.95
3[c]	Raw	0.84	0.71	0.75
	Weighted	1.00	0.62	0.75
4, 5, 6[d]	Raw	0.70	0.43	1.05
	Weighted	1.07	0.44	1.05

[a]Based on number of accidents.
[b]Weighted by section lengths.
[c]62 accidents at 1.65-HFC level not considered as valid low point.
[d]28 accidents at 1.95-HFC level not considered as valid low point.

For class 3 streets, the unweighted data on night-day accident costs showed a ratio of 1.5 at the optimum illumination level of 0.8 HFC. For collector streets, the data were not entirely consistent, but it appeared that an accident cost ratio of 1.0 would be appropriate when these routes were lighted to the optimum level of 1.0 HFC.

The total day accident costs for each range of maintained footcandles in each of the street classes can be multiplied directly by the night-day accident cost ratio. If the resulting value is then subtracted from the actual cost of nighttime accidents in each footcandle range, the difference will be the cost that might be saved by illumination of the route to the optimum values. Such calculations were made for each of the class groupings, and the potential accident cost savings are given in Table 5. Because of the uncertainties of the exact optimum or design illumination levels for each grouping, the potential cost savings were calculated only for those groups below the range in which the design level applied. Using this method of calculation and assuming that the routes had been lighted to the indicated levels, we estimated a potential savings of some $4 million in accident costs for calendar year 1967.

Theoretically, accident costs would have been further reduced if some of the more brightly lighted routes had a lower level of illumination. However, data are not adequate to justify reducing existing lighting levels. More extensive studies might or might not produce such justification. Furthermore, the study was limited strictly to accident implication, without regard to other elements such as personal security or police needs.

The cost to provide the additional lighting to reach the design levels was estimated in order to develop benefit-cost ratios. In this step, lighting systems were designed and costs were estimated for a substantial number of individual sections for various street classifications. The added costs were calculated on a per mile basis by first subtracting the cost of existing lighting and then factoring the section length to a full mile. The average added cost for improvements in illumination for the various existing levels and street classes is given in Table 6. Also given are the mileages of each illumination group and the estimated annual cost to bring the lighting levels up to the assumed design values.

Direct benefit-cost ratios were calculated for each of the 3 combined classes of streets and are as follows:

Class	Ratio
1, 2	22:1
3	60:1
4, 5, 6	5:1

The greatest apparent benefit would lie in upgrading class 3. This is largely because the change in illumination would be the smallest of any of the classes and, hence, the added lighting cost would be minimal. Because of the statistical limitations, further study might indicate a somewhat different illumination level. If the desirable level were higher, it would reduce the benefit-cost ratio. Whatever adjustments are made, however, it appears that substantial benefits would be realized by upgrading lighting intensity on all of the major and collector streets.

SUMMARY OF FINDINGS

1. Streets with little or no illumination had substantially higher night-day accident ratios and accident cost ratios than the average for all streets in their respective groups. Inadequate lighting, therefore, contributes to accident hazards.

2. The type of street appears to be more of a factor in accident-illumination relations than is the type of abutting land use.

3. Streets with extremely high illumination levels tended to have night-day accident and accident cost ratios that were above the average for each group. It appears possible to "overlight" as well as to "underlight" a given street. However, data on several other important factors (such as streetlight glare, background storefront lighting, or sign lighting) were not evaluated.

Figure 5. Relation between illumination level and accident experience for class 1 and class 2 streets.

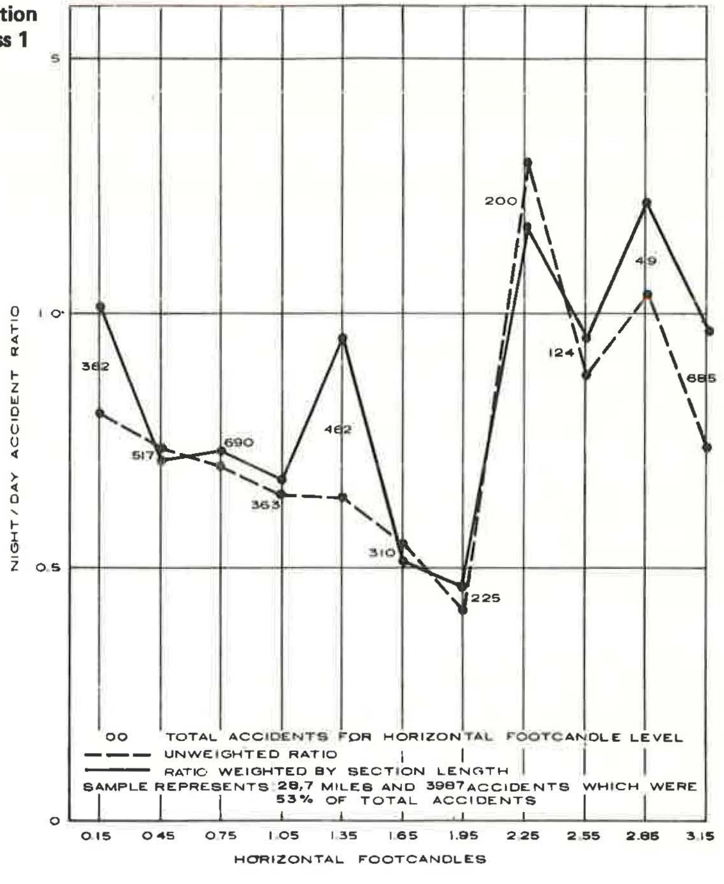

Table 5. Potential accident cost savings if streets are lighted to optimum levels.

Class	Night-Day Accident Cost Ratio[a]	Design Illumination Level (HFC)	Savings (millions of dollars) by Existing Illumination					
			0.00-0.29	0.30-0.59	0.60-0.89	0.90-1.19	1.20-1.50	Total
1, 2	0.8	1.8	0.470	0.729	0.258	0.135	0.243	1.835
3	1.5	1.5	0.930	0.680	—	—	—	1.610
4, 5, 6	1.0	1.0	0.337	0.199	0.058	—	—	0.594
Total			1.737	1.608	0.316	0.135	0.243	4.039

[a]Produced if existing illumination is upgraded to new design level.

Table 6. Costs of upgrading lighting.

Class	Illumination (HFC)	Sections Number	Sections Percent	Added Cost/Mile[a] (dollars)	Miles Number	Miles Revised[b]	Miles Upgraded	Annual Cost (dollars)
1, 2	0.00-0.29	5	46	4,300	5.1	0	5.1	22,000
	0.30-0.59	8	50	5,100	5.5	0	5.5	28,000
	0.60-0.89	12	75	3,200	6.4	0	6.4	21,000
	0.90-1.19	5	56	3,400	2.9	0.3	2.6	9,000
	1.20-1.49	7	47	2,300	2.1	0	2.1	5,000
	Total							85,000
3	0.00-0.29	14	50	2,200	14.0	4.9	9.1	20,000
	0.30-0.59	8	44	1,100	7.7	1.2	6.5	7,000
	Total							27,000
4, 5, 6	0.00-0.29	17	20	3,800	28.0	0.4	27.6	105,000
	0.30-0.59	8	42	2,200	4.0	0	4.0	9,000
	0.60-0.89	14	48	1,200	10.8	0	10.8	13,000
	Total							127,000

[a]Average of sections checked. [b]Since 1967.

4. The apparent minimum (most favorable) night-day ratios of both number of accidents and accident costs were associated with the following illumination levels:

Class	Level (HFC)
1, 2	1.8
3	0.8
4, 5, 6	1.0

5. A substantial benefit-cost ratio would result if lighting on various street sections were upgraded to the values given above.

6. The methodology developed during the project is felt to represent a major contribution to the techniques of making such a study. The data were generally adequate to justify establishments of priority for systematically upgrading illumination of major and collector streets in Syracuse to minimize nighttime accidents and to maximize economic benefits.

ACKNOWLEDGMENT

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REFERENCES

1. American Standard Practice for Roadway Lighting. Illuminating Engineering Society, 1963.
2. Motor Vehicle Accident Costs. Wilbur Smith and Associates, 1966.