FREEWAY ACCIDENTS AND ILLUMINATION

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The findings of a study of freeway accidents and illumination are reported. The time during which ambient light conditions are such that typical roadway illumination would have an effect was found to be from 15 min after sunset to 15 min before sunrise. Lighted freeways were found to have lower (better) night-day accident ratios than unlighted ones. The lighted freeways with the lowest illumination, averaging 0.6 horizontal footcandles maintained, had the best accident ratio. This corresponds to an initial illumination design level of about 1.0 HFC. A wide variation was found in average illumination between adjacent pairs of luminaires along specific freeway sections. This was found to be principally a result of differences in individual lamp output. The variations of HFC averages and uniformity are so great as to cast doubt on the real value of these elements in lighting design calculations.

•IN THE 1966 public lighting needs report to the U.S. Congress, data were presented from pilot studies of freeway accidents (1). Information was related to estimated vehicle-miles of travel, night-day accident ratios, illumination levels, and uniformity. Apparent trends were found in reduced night-day accident ratios (hence, actual reductions in accidents) with increased illumination and with improved uniformity. However, the illumination levels were calculated in-service values as reported by the responsible public agencies.

A study, undertaken in the Illuminating Engineering Research Institute, was designed to expand the data base and to attempt definition of optimum illumination levels and uniformities from the standpoint of accident reduction. In the execution of the study. careful attention was given to tabulation of accidents from the reports themselves (to eliminate computer data errors) and to collection of traffic volume counts. The attempt was made to include a wide variety of urban and suburban freeway conditions, such as number of lanes, traffic volumes, and illumination levels and uniformities, including no illumination.

Data were gathered from metropolitan areas of Toronto, Chicago, Atlanta, Dallas, Phoenix, and Denver. There were 203 miles of routes and more than 21,000 accidents included in the summary. Items tabulated from each accident report included time of accident and weather condition, accident severity, type of accident, portion of freeway roadway on which the accident occurred (main line, ramp exit from main line, ramp entrance to main line, and entirely within the ramp itself), and age of the driver who struck another object or who ran off the road (not necessarily the driver who was legally responsible for the accident).

Figure 1 shows the card used to code the accident data, and Table 1 gives a summary listing of all routes that were studied.

From the standpoint of tabulation, a location type of accident file is highly desirable. The tabulation of accident data from copies of the police report can be time-consuming, but it appears to be a necessary control. The number of accidents directly relatable to freeway illumination was found to vary widely in the check between actual tabulations and data processing printouts. In a check of 3 systems, differences of 19 to 62 percent were found.

DAY-NIGHT THRESHOLD POINT

An important initial step in the project was to find a method of accurately relating freeway accidents and traffic volumes to illumination. This, in part, required

Figure 1. Accident coding card.

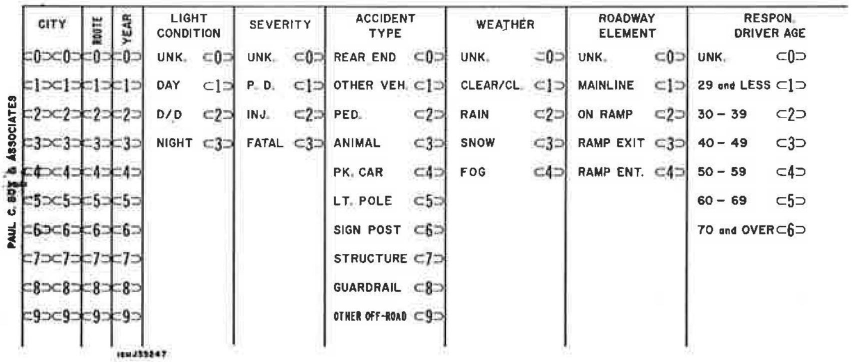


Table 1. Summary of route data.

Route	Length (miles)	Data Years	Accidents Day	Accidents Night	Accidents Total	Million Vehicle-Miles	Accidents/MVM Day	Accidents/MVM Night	Accidents/MVM Total	Night-Day Ratio	Area	Lighting
4 Lanes												
I-85, DeKalb County	8.8	64-67	888	356	1,244	523	2.29	2.63	2.38	1.15:1	Suburban	No
I-85, Atlanta	3.4	64-67	2,184	697	2,881	356	8.32	7.49	8.11	0.90:1	Urban	Yes
I-75, Atlanta	3.8	64-67	989	266	1,255	276	4.82	3.75	4.54	0.82:1	Urban	Yes
401 Toronto	43.0	64-66	570	466	1,036	945	0.81	1.89	1.10	2.33:1	Rural	No
400 Toronto	40.6	64-66	484	347	831	617	1.06	2.17	1.34	2.05:1	Rural	No
I-25, Denver	5.0	65-66	120	75	195	130	1.20	2.50	1.50	2.08:1	Suburban	Yes
N.C. sec. 1, Dallas	3.3	65-67	438	182	620	193	2.98	3.96	3.20	1.31:1	Suburban	Yes
N.C. sec. 2, Dallas	2.2	65-67	599	140	739	150	5.20	3.88	4.92	0.73:1	Urban	Yes
Ill-394 sec. 8, Chicago	3.5	65-68	83	77	160	unk.	unk.	unk.	unk.	2.80:1	Suburban	No
Ill-394 sec. 9, Chicago	1.5	65-68	22	21	43	unk.	unk.	unk.	unk.	2.90:1	Suburban	No
6 Lanes												
Q.E.W., Toronto	5.5	63-65	417	240	657	237	2.74	3.88	2.77	1.42:1	Urban	Yes
I-25, Denver	7.0	65-66	514	249	763	150	4.47	7.11	5.08	1.59:1	Urban	Yes
M-39, Detroit	8.0	65-66	484	334	818	unk.	unk.	unk.	unk.	2.07:1	Urban	Yes
I-17, Phoenix	6.3	63-66	410	207	617	320	1.68	2.69	1.93	1.63:1	Urban	Yes
N.C. sec. 3, Dallas	1.9	65-67	716	180	896	159	5.90	4.80	5.63	0.81:1	Urban	Yes
I-75/85, Atlanta	2.0	65-67	1,182	459	1,641	174	9.24	9.98	9.44	1.08:1	Urban	Yes
I-20 sec. 7, Atlanta	2.8	64-67	407	205	612	214	2.55	3.73	2.86	1.46:1	Urban	Yes
I-20 sec. 6, Atlanta	1.0	66-67	198	59	257	51	5.10	4.40	4.91	0.87:1	Urban	Yes
I-294 sec. 2, 6, Chicago	9.8	60-67	428	270	698	976	0.59	1.06	0.72	1.80:1	Suburban	No
I-294 sec. 0, 5, Chicago	4.4	60-67	126	71	197	439	0.39	0.62	0.45	1.59:1	Suburban	Partial
I-294 sec. 3, Chicago	1.7	60-67	52	40	92	127	0.55	1.21	0.73	2.20:1	Suburban	Yes
I-294 sec. 1, 4, Chicago	0.8	60-67	192	72	264	75	3.50	3.60	3.51	1.02:1	Suburban	Yes
I-55 sec. 1-4, Chicago	2.7	65, 66, 68	286	167	453	unk.	unk.	unk.	unk.	1.90:1	Urban	Yes
I-55 sec. 0, 7-9, Chicago	7.2	65, 66, 68	210	166	376	unk.	unk.	unk.	unk.	2.40:1	Urban	Yes
I-55 sec. 5, Chicago	2.3	65, 66, 68	135	80	215	unk.	unk.	unk.	unk.	1.80:1	Urban	Yes
I-55 sec. 6, Chicago	4.0	65,66, 68	287	144	431	unk.	unk.	unk.	unk.	1.50:1	Urban	Yes
I-94 sec. 2, Chicago	1.5	65-68	124	159	283	unk.	unk.	unk.	unk.	3.80:1	Urban	Yes
I-94 sec. 1, Chicago	1.2	65-68	243	184	427	unk.	unk.	unk.	unk.	2.70:1	Urban	Yes
I-94 sec. 3, Chicago	0.5	65-68	156	96	252	unk.	unk.	unk.	unk.	1.80:1	Urban	Yes
I-94 sec. 0, 4, Chicago	2.1	65-66	89	91	180	113	1.06	3.19	1.59	3.00:1	Urban	No (before)
I-94 sec. 0, 4, Chicago	—	68	58	27	85	66	1.18	1.59	1.29	1.30:1	Urban	Yes (after)
I-94 sec. 5-7, Chicago	3.2	65-66	105	105	210	153	0.93	2.72	1.37	2.90:1	Urban	No (before)
I-94 sec. 5-7, Chicago	—	68	79	53	132	86	1.22	2.45	1.53	2.00:1	Urban	Yes (after)
8 and 10 Lanes												
I-75/85, Atlanta	1.1	66-67	434	131	565	90	6.48	5.70	6.29	0.88:1	Urban	Yes
401, Toronto	2.6	66	180	97	277	96	2.54	3.88	2.93	1.53:1	Urban	Yes
I-20, Dallas	4.6	66-67	258	93	351	217	1.61	1.65	1.61	1.01:1	Urban	Yes
I-35, Dallas	4.2	66-67	512	186	698	275	2.43	2.83	2.52	1.15:1	Urban	Yes
Total	203.5				21,439	7,131+						

determination of whether specific accidents coded as occurring at dusk or dawn happened during a night condition when artificial illumination could have been of value. The actual amount of night traffic on each route needed to be calculated so that accident rates per million vehicle-miles (MVM) could be separately computed for day and for night travel.

The method used to establish the cutoff point between natural daylight and night when artificial street lighting was needed had to apply to any location. It had to account for latitude and longitude, regardless of season.

Artificial light is normally not needed immediately after sunset (or before sunrise). It becomes clearly necessary prior to the time of civil twilight, defined as the time at which the center of the sun's disk is 6 deg below the local horizon. The time of civil twilight occurs between 30 and 40 min after sunset (or before sunrise) and is close to the point where natural daylight is nearly undiscernible.

Civil twilight was used as a guide in a series of tests that were made in the Chicago area to measure the HFC decay after sunset or its buildup before sunrise. The results of part of the twilight measurements are shown in Figure 2. This shows the change in ambient illumination after sunset in January, April, and July. These times represent the 3 near-extreme conditions of sunrise and sunset daylight rate of change. In the threshold area, the curves are separated by only about 2 min.

For lighting purposes, it was assumed that the threshold point lay midway between sunset-sunrise and civil twilight. This point was originally estimated by visual checks. Figure 2 shows ambient values of 1.5 to 4.9 HFC at this point. A change of only 6 min ($^1/_{10}$ hour) produces a drop to a level of 1 or 2 footcandles for even the higher value. In this immediate area then, a point of ambient illumination is reached when artificial lighting levels typically used on roadways (0.5 to 1.5 HFC) represent a significant added factor in driver visibility.

The same results were found for a sunrise condition, with even less difference among the seasonal light change values. The range in ambient illumination at the "assumed dark" point was 0.9 to 3.3 HFC.

A close approximation of the threshold point occurs 15 min before sunrise and 15 min after sunset. Checks were made with moderate to heavy cloud cover, but only about a 5-min variation was found in the basic assumed dark threshold point.

Estimates were also made on extremely cloudy days with precipitation. Variation in threshold time was found to be only about 10 to 15 min. Because relatively few days of the year have this extreme condition, it was felt this should not make a significant difference. Accident reports seldom reflect the time of an accident closer than 5 min. Traffic volumes are not perfectly spread during each minute of the threshold hours.

NIGHT TRAFFIC

From the volume studies, on an hour-by-hour basis, the finding was made that 25 percent of urban freeway traffic consistently moves at night. Latitude, longitude, local DST practice, and metropolitan area size appear to cause no significant variation.

This is an important finding, for it allows direct calculation of rate ratios in the absence of traffic counts. The night-day ratio (per million vehicle-miles or any other travel exposure measure) is mathematically equal to 3 times the number of night accidents divided by the number of day accidents.

LIGHTING MEASUREMENTS AND VARIATIONS

Most measurements of existing lighting were taken under "live" traffic conditions between 2:00 and 5:00 a.m. Measurements were made at 14 freeway locations. These were chosen to be as representative as possible of typical spacing for each route. Readings at 10 sites were taken directly below 2 to 7 adjacent luminaires. For each location these "below-luminaire" HFC readings were tabulated and averaged. Grid readings were then taken between the pair of luminaires that best represented an average. Points were chosen along pavement edges and at quarter-spacing transverse lines.

From the grid readings, typical in-service illumination and uniformity ratios were determined. The initial design values were calculated from manufacturers' photometric curves. Lamp correction factors were applied, based on the types of lamps actually in use at the time of measurement. Measured and calculated data were then compared to produce typical examples of in-service depreciation.

Comparison of the point-by-point grid measurements with calculated initial design data for the 10 locations showed light losses ranging from 18 to 72 percent. The average was 49 percent for an average system age of nearly 8 years. Depreciation for installations as old as 7 years averaged 47 percent, and systems 8 to 15 years old averaged 54 percent.

All of the below-luminaire readings in 10 sections were compared with calculated initial illumination for this point, and depreciations of 35 to 73 percent were found. The overall average light loss was 51 percent, as measured by this rough approximation method, which thus compared favorably with the 49 percent average from the grids.

In-service uniformity ratios (average-to-minimum) found in the grid measurements were worse than the calculated initial values in all but 2 cases. The average change was 58 percent for those that became worse. At one location where grid readings were made, the nearby contributing luminaires were cleaned and new grid readings taken. The direct effect of this cleaning was to increase the average illumination from 0.45 to 0.50 HFC (an increase of 10 percent). However, the cleaning worsened the average-to-minimum uniformity ratio, from 9:1 before to 10:1 after.

The first 10 test sections involved practices of burnout replacement of lamps rather than group replacement. In practically all of these cases, the only luminaire cleaning performed was at the time of lamp replacement (or pole knockdown). In fairness to the cooperating agencies in this study, it should be reported that several were beginning programs of improved maintenance.

Depreciation factors were also compared at 4 locations of equal age (4.5 to 4.7 years). Two systems had burnout replacement and luminaire washing only at burnout, and the other 2 had group replacement at 16,000 hours (about every 4 years) plus annual washing. An average depreciation of 54 percent was found for the poor maintenance systems versus only 36 percent for the group maintenance. This offers evidence in favor of group replacement programs, which are endorsed by most engineers. However, depreciation in uniformity ratio was just as bad under one maintenance system as another.

The city of Philadelphia requires its maintenance contractor to regularly test mercury lamps removed from service during group replacement programs. The testing involves comparison against "standard" lamps, and data are tabulated on the percentage of lumen output of the lamp being tested. The date of lamp installation is placed on the base, and the date of removal is known. It is, therefore, possible to compare months in service with lumen output (expressed as percentage of a 100 percent standard).

Data from 804 such tests were secured from the contractor. Findings are given in Table 2. Wide variations can appear early in lamp service. Most group replacement is performed at a 3- to 4-year lamp life. The extremes in output of 40 to 94 percent, as compared with the 78 percent average for this length of life, are equivalent to a range of -49 to +21 percent of the average. The range for all lamp ages, as compared with the 67 percent overall average, is an example of what might be expected in the field under a burnout replacement program; this variation was -52 to +33 percent.

These laboratory findings were compared with the below-luminaire readings from each freeway route section. The field readings were expressed as a percentage of the average of the 2 lamps at the "typical" test locations. This was done separately for each of the 8 routes so the problem of different types of luminaires would be eliminated. The extreme reading variations were then averaged. The limits thus found ranged from a low of -49 percent to a high of +66 percent for the routes with burnout replacement systems. The range was -40 to +69 percent for the group replacement routes.

The field data show an excellent fit with the laboratory findings on the low end of the scale but a poor fit on the upper end. They are sufficiently in agreement, however, to sustain the hypothesis that freeway illumination usually varies about 50 percent on either side of any "nominal" value measured in the field.

The ±50 percent variation occurs under ideal conditions of constant geometry and spacing to mounting height ratios. When the actual spacing and variable-roadway width differences (such as those that occur at ramp entry or exit points) are considered, an even wider range exists in the hypothetical "average" HFC.

The foregoing findings in actual roadway illumination show such extremes in HFC averages and uniformity (average-to-minimum) that serious doubt is cast on the value of such elements in lighting design. The erratic performance of systems certainly invalidates any analysis of fine differences among various designs. The subject research assignment was to investigate relatively small differences in lighting and to search for nominal design values. However, the extent of variations may be enough to "wash out" meaningful analysis. For example, a variation of 50 percent produces in an 0.8-HFC nominal system a range from 0.4 to 1.2 in area averages at random locations. Another system with doubled nominal illumination of 1.6 HFC will vary from 0.8 to 2.4. This obviously overlaps well into the first system.

In order to achieve reasonable separation, a threefold difference appears to be needed in nominal level (such as 0.6 versus 1.8 HFC). Extremes of this magnitude were generally not located for study in the subject research.

LIGHTED VERSUS UNLIGHTED ROUTES

As a group, the lighted freeways for which data are given in Table 1 had an average night-day ratio of 1.43 for all types of accidents. The unlighted freeway average was 2.37. If a freeway experiences 1,000 day accidents during any time period, the expected number of night accidents can be calculated for any assumed night-day rate ratio. The lighted average ratio of 1.43 produces 475 night accidents by use of the equation $E_N = R\,A_D/3$, where E_N = expected number of night accidents, R = night-day rate ratio, and A_D = number of day accidents.

The unlighted average ratio of 2.37 produces 790 night accidents. The difference is 315, which represents 40 percent fewer night accidents. If compared with the 1,790 total of day and night accidents, the average overall reduction would be 18 percent.

This example indicates that the illumination of an unlighted urban freeway could theoretically reduce night accidents by an average of 40 percent or overall accidents by 18 percent.

If only the fatal and injury accidents are considered, the night-day ratio is 1.69 for lighted freeways and 3.53 for unlighted ones. A lighted freeway with 1,000 fatal and injury accidents during the day would average 560 such accidents at night. If unlighted, however, there would be 1,180 such night accidents. The apparent effect of lighting on the fatal and injury accidents is a reduction of 52 percent in night accidents.

The statistical analysis involved a chi-square test for association between accident rate ratios and the presence or absence of lighting. A total of 59 observations were available, 18 of which involved unlighted route sections. (An "observation" is 1 year of data from 1 section. Thus, 1 route with 3 years of data produces 3 observations.) The data were entirely adequate to allow the test to be performed. The test established that lighted freeways as a group have lower rate ratios for all types of accidents than unlighted freeways. A highly significant (1 percent) value of chi-square was found. This means that less than 1 possibility in 100 exists for a chance occurrence. Testing of only the fatal and injury accidents resulted in a similar finding that was significant at the 5 percent level (less than 5 possibilities in 100 exist for a finding due to chance alone).

BEFORE-AND-AFTER STUDY

In the Chicago area, an opportunity was found to compare accidents before and after relighting 5.3 miles of 6-lane urban freeway. Unfortunately, resurfacing and minor reconstruction along the route were commenced about 1 year after installation of the lighting. The after period of study was thus limited to only 1 year. Data were available for 2 years in the before period, however.

The study route was Interstate 94 between 132nd Street and 167th Street. This route had a narrow median (12 ft) between 132nd Street and 146th Street. In the rest of the lighted section, the median width was 33 ft.

Study findings from each section are given in Table 3. A direct reduction occurred during the after period in all types of accidents. A large change in the number of accidents per MVM is also found. However, the total number of accidents is less than 600 for all 3 years of data from both sections.

Figure 2. Seasonal effect of ambient illumination.

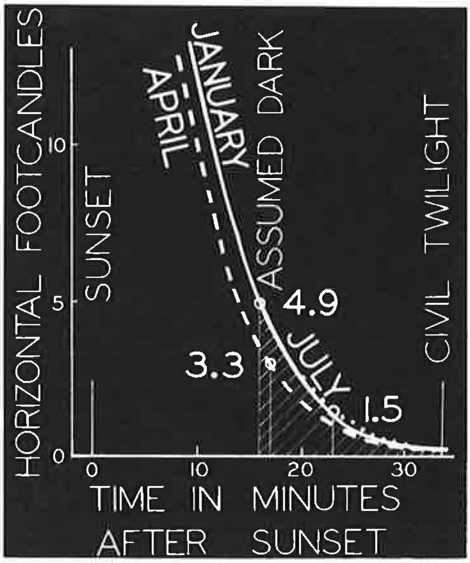


Table 2. Lamp output as function of service.

Months in Service	Number Tested	Percentage of Standard Lamp: Low	High	Average
Under 24	15	54	98	79
24 to 35	70	46	94	75
36 to 47	83	40	94	78
48 to 59	171	30	94	70
60 to 71	210	16	88	66
72 to 83	126	20	90	65
84 to 95	113	18	84	53
Over 95	24	30	74	50
Total	804	32	89	67
Variation from avg		-52	+33	

Table 3. Results of before-and-after lighting study.

		Before					After				
		All Accidents			Injury-Fatal Accidents		All Accidents			Injury-Fatal Accidents	
Freeway Location	Time	Number	Percent	Per MVM	Number	Percent	Number	Percent	Per MVM	Number	Percent
132nd to 146th	Day	40	47	1.06	15	39	29.	68	1.18	17	63
	Night	46	53	3.19	23	61	14	32	1.59	10	37
	Total	86	100	1.59	38	100	43	100	1.29	27	100
146th to 167th	Day	105	51	0.93	30	37	79	60	1.22	30	60
	Night	105	49	2.72	52	63	53	40	2.45	20	40
	Total	210	100	1.37	82	100	132	100	1.53	50	100

The night-day accident ratios were as follows:

Location	Before	After
132nd to 146th	3.0:1	1.3:1
146th to 167th	2.9:1	2.0:1

The chi-square test was applied to the night-day ratios. The probability of the difference in rates being due to chance occurrence was found to be less than 1 in 100 (a chi-square value significant at 1 percent). This result suggests that the accident rate ratio is significantly lower after lighting was installed. However, the data consist of only 12 observations, which does not fulfill the generally accepted requirements of at least 20 observations for a 2 by 2 chi-square contingency test (each cell should have an expected value of at least 5). Hence, the result of this test must be treated with some caution.

As a second statistical test, it was assumed that any trend in day accident figures would also be representative of any trend in night accidents. From the day values for the 2 study sections, a trend was established during the period covering both the before and the after conditions. This trend was applied to the before night figures to obtain the expected number of accidents during the after period, if lighting had not been installed. A t-test was then performed on the difference between this expected figure and the actual figure after installation of lighting. The t-value for both sections together was significant at the 10 percent level. For the north section only, a t-value of 5 percent was found.

These tests indicate that the installation of lighting quite possibly lowered the night accident rate, but an exhaustive statistical confirmation is lacking.

LIGHTED VERSUS UNLIGHTED SECTIONS OF SAME ROUTE

Interstate 85 in Atlanta is lighted, but its extension in DeKalb County is unlighted. Direct comparison studies were performed in which 2 years of data from the lighted section and 4 years from the unlighted section were used.

The lighted portion is 3.4 miles in length and extends northeast from a major interchange point. The basic design consists of two 24-ft roadways with a 14-ft median. There are 4 interchanges along this section, in addition to the main freeway junction. The junction is of a directional type, and the interchanges are essentially of the diamond type. During the 1966 and 1967 study period, the route experienced 189 MVMT. Fixed lighting utilizes a 28-ft mounting height, type 3 distribution, 6-ft overhang, and 120-ft staggered spacing. Measurements taken at an interchange location on the route during 1967 showed a maintained illumination level of 0.38 HFC and a uniformity ratio of 2.7 to 1. However, subsequent measurements in a location more typical of the overall route average found a level of 0.33 HFC and a uniformity ratio of 16 to 1.

The unlighted section is 8.8 miles in length and is generally similar to the lighted portion except for a wider median and lower traffic volume. The section has 7 interchanges, generally of the diamond type. One is a major interchange with a partially completed circumferential freeway loop. During the 1963 to 1967 study period, the unlighted section had 523 MVMT.

The relation of the number of accidents, roadway elements, and day or night conditions is given in Table 4. The accidents have been grouped into the following types:

Accident	Type
Rear end	1
Other vehicular	2
Pedestrian and parked car	3
Fixed object and other off-road	4

The day and night accidents/MVM and the night-day ratios are also given in Table 4. (Ratios are omitted where only small accident sample sizes were available.) A substantial difference in direct accident rates exists between the 2 sections. It is, therefore, necessary to relate these rates on a ratio basis. The ratios for the unlighted route are higher for type 1 than for type 2 accidents. Conversely, the ratio for type 3 accidents is higher for the lighted section. (A larger night-day ratio indicates a correspondingly more hazardous night condition.) Certain accident types and roadway elements predominate as the percentages given at the bottom of Table 4 show.

These data show that certain apparently dangerous locations actually had relatively few accidents. Such locations include the exit ramp, or gore position, and the ramps themselves. Type 4 accidents at these locations accounted for only 1 percent of the accidents on the lighted section and 2 percent on the unlighted section.

Primary accident problems in the study sections involve rear-end collisions. The high concentration of such accidents at ramp entrances can be partially traced to lack of adequate acceleration lanes. The unlighted section had better designs in this respect.

INTERCHANGE LIGHTING

In several route sections, accidents were tabulated separately in the interchange areas (between extreme ends of exiting and entering ramp tapers) and areas between the interchanges. The percentage of night accidents occurring within each grouping was chosen as the best means of comparison. Summary data are given in Table 5. In most of the cases, a higher percentage of accidents occurred at night between the interchanges. This appears to be a characteristic that is not changed by lighting. The before-and-after sections show an even more pronounced difference after lighting was installed. A check was made of 5 freeway sections having 4,000 accidents. From 29 to 79 percent of all the section accidents occurred between interchanges. The average for all 5 sections was 50 percent. Data such as these should generate careful review of policies that favor interchange lighting over continuous lighting.

LIGHT-POLE COLLISIONS

Most of the lighted routes studied had relatively standard mounting heights of 28 to 33 ft. Thus, the better illuminated routes had closer pole spacing. One 4-lane section with a measured HFC average of 0.50 had 35 poles/mile, and an adjacent section of the same 4-lane route with a 1.1 HFC had 66 poles/mile. The lower lighted route had 739 total accidents, 8 of which (1.1 percent) involved light poles as a first significant object struck. The total exposure (poles/mile × MVM) was 5,250 MV, or 655 MV/pole accident.

The higher lighted route had 620 accidents, 17 of which involved light poles (2.7 percent). Thus, an increase of 90 percent in the number of poles/mile also numerically increased the number of pole accidents by 90 percent. The pole percentage of total accidents was 2½ times as great. The exposure was 12,700 MV for the higher lighted route, which is also 2½ times that of the lower lighted route. The route had 1 pole accident/745 MV.

A third route checked had 8 lanes, 0.9-HFC illumination, and 80 poles/mile. This route had 698 accidents during the study period; 27 (3.9 percent) involved light poles. The total exposure was 22,000 MV or 815 MV/pole accident.

On a vehicle mileage basis, 2 lower lighted routes experienced rates of 0.05 and 0.06 pole accidents/MVM. The 2 better lighted route rates were 0.09 and 0.10/MVM. Thus, doubling the number of poles increased the actual number of pole accidents and tended to double the accident mileage rate involving poles.

EFFECT OF ILLUMINATION LEVEL

The routes selected for study have a wide range in accident rates. These vary from a low of 0.39 to a high of 9.24/MVM during the day. At night, the range is 0.62 to 9.98/MVM. The average overall rate (for the routes with volume data) is 3.25/MVM.

From the standpoint of testing a broad range of different conditions of congestion, geometric design, climate, and metropolitan area size, the variety of route sections is highly desirable. The magnitude of differences, however, clearly precludes any direct comparison of accident rates, and analysis of lighting effect required use of the night-day ratio of rates.

During the early part of this research, it was still assumed that field measurements on a sampling basis would provide a narrow range of factors, which could be used to relate calculated and actual field lighting levels and uniformities. It was assumed that

Table 4. Summary of accidents in I-85 study.

Item	Lighted Section Type 1	Lighted Section Type 2	Lighted Section Type 3	Lighted Section Type 4	Unlighted Section Type 1	Unlighted Section Type 2	Unlighted Section Type 3	Unlighted Section Type 4
Number of Day Accidents								
Main line	284	93	3	88	306	110	7	123
Ramp entrance	574	25	1	2	301	24	1	0
Ramp exit	2	4	0	1	6	6	1	6
On-ramp	3	1	0	1	1	2	2	3
Total	863	123	4	92	614	142	11	132
Number of Night Accidents								
Main line	77	30	10	90	90	61	9	90
Ramp entrance	119	14	0	4	83	3	0	1
Ramp exit	2	4	0	6	3	5	1	9
On-ramp	0	0	1	2	C	0	1	2
Total	198	48	11	102	176	69	11	102
Night-Day Ratio								
Main line	0.79	0.92	—	2.92	0.83	1.61	—	2.00
Ramp entrance	0.59	—	—	—	0.78	—	—	—
Ramp exit and on-ramp	—	—	—	—	—	—	—	—
Overall	0.65	1.11	—	3.16	0.82	1.41	—	2.23
Accidents/MVM								
Day	6.15	0.88	—	0.66	1.58	0.36	—	0.34
Night	4.02	0.98	—	2.08	1.30	0.51	—	0.76
Percentage of Section Accidents								
Main line	25	9	12	1	31	14	17	1
Ramp entrance	48	3	—	—	30	2	—	—
Ramp exit and on-ramp	—	1	1	—	1	1	2	1
Total	73	13	13	1	62	17	19	2

Table 5. Percentage of night accidents within and between interchanges.

Route	Type of Interchange	Unlighted Within	Unlighted Between	Lighted Within	Lighted Between
I-85, DeKalb County		25	33	—	—
I-94 sec. 3, Chicago	Cloverleaf	—	—	38	—
I-94 sec. 1-2, Chicago	Diamond	—	—	43	56
I-94 sec. 0, 4, Chicago	Cloverleaf	46[a]	52[a]	25[b]	34[b]
I-94 sec. 5-7, Chicago	Cloverleaf	49[a]	52[a]	36[b]	43[b]
Ill-394 sec. 8-9, Chicago	Cloverleaf	49	48	—	—
I-55 sec. 0-4, 7-9, Chicago	Cloverleaf	—	—	42	38
I-55 sec. 5-6, Chicago	Diamond	—	—	33	37

[a]Before. [b]After.

Table 6. Illumination of urban and suburban route sections.

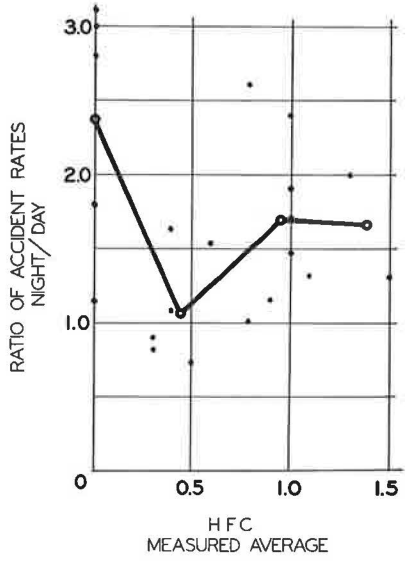
Route	Accidents/ MVM Day	Accidents/ MVM Night	Night-Day Ratio	Illumination HFC	Illumination Uniformity
4 Lanes					
I-85, DeKalb County	2.29	2.63	1.15:1	0	–
I-85, Atlanta	8.32	7.49	0.90:1	0.3	16.0:1
I-75, Atlanta	4.82	3.75	0.82:1	0.3	16.0:1
N. C. sec. 1, Dallas	2.98	3.96	1.31:1	1.1	3.2:1
N. C. sec. 2, Dallas	5.20	3.88	0.73:1	0.5	3.6:1
Ill-394 sec. 8-9, Chicago	–[a]	–[a]	2.80:1	0	–
6 Lanes					
I-17, Phoenix	1.68	2.69	1.63:1	0.4	15.0:1
N. C. sec. 3, Dallas	5.90	4.80	0.81:1	0.3	7.5:1
I-75-85, Atlanta	9.24	9.98	1.08:1	0.4	4.0:1
I-20 sec. 7, Atlanta	2.55	3.73	1.46:1	1.0	20.0:1
I-294 sec. 2, 6, Chicago	0.59	1.06	1.80:1	0	–
I-55 sec. 1-4, Chicago	–[a]	–[a]	1.90:1	1.0	3.7:1
I-55 sec. 0, 7-9, Chicago	–[a]	–[a]	2.40:1	1.0	2.5:1
I-55 sec. 5-6, Chicago	–[a]	–[a]	1.70:1	1.0	–[b]
I-94 sec. 1-3, Chicago	–[a]	–[a]	2.60:1	0.8	2.7:1
I-94 sec. 0, 4, Chicago	1.06	3.19	3.00:1	0	–
I-94 sec. 0, 4, Chicago[c]	1.18	1.59	1.30:1	1.5	4.5:1
I-94 sec. 5-7, Chicago	0.93	2.62	2.90:1	0	–
I-94 sec. 5-7, Chicago[c]	1.22	2.45	2.00:1	1.3	4.0:1
8 and 10 Lanes					
I-20 sec. 4, Dallas	1.61	1.65	1.01:1	0.8	3.5:1
I-35 sec. 7, Dallas	2.43	2.83	1.15:1	0.9	5.1:1
401 Toronto[d]	2.54	3.88	1.53:1	0.6	1.8:1

[a]Insufficient traffic counts to establish MVM rate. Ratio calculated from night percentage.
[b]Two sections with differing uniformities, combined.
[c]After lighting.
[d]Not used in statistical tests.

Table 7. Relation between illumination and night-day accident ratio.

Illumination (HFC)	Number of Samples	Night-Day Accident Ratio All	Night-Day Accident Ratio Injury-Fatal
Lighted			
0.3 to 0.6	7	1.07	1.40
0.8 to 1.1	8	1.69	1.93
1.3 to 1.5	2	1.65	1.85
Avg	17	1.43	1.69
Unlighted	5	2.37	3.53

Figure 3. Accident ratios and average illumination.



the summary data would be usable from 14,000 Chicago and Detroit accidents, as gathered in the public lighting needs study. When a correlation between calculated and measured values was not found, it was decided to not use any accident data from lighted routes, unless field measurements were available.

Twenty-two route sections were usable for the basic illumination analysis. These are given in Table 6. The day and night accident rates, the night-day ratios of these rates, and the results of illumination measurements are also given.

Table 7 gives a comparison of lighted and unlighted groups. Rate ratios are given for all accidents and for only fatal and injury accidents. Rates for all accidents are shown in Figure 3. The sections with a lighting level between 0.3 to 0.6 HFC had the best ratio of night-day accident rates. A chi-square test established that this group had a very significantly lower ratio (the probability of this being a chance finding is less than 1 in 1,000). Testing of only fatal and injury accidents resulted in a similar finding. The sections with higher illumination values appear to level off at an average ratio between 1.6 and 1.7. The higher illumination group was tested against the unlighted group, and no significant difference was found. The chi-square values, however, suggest that there is a utility in the higher illuminated freeways, as compared with unlighted ones, even though the data did not allow significant differences to be established.

The data do not allow specification of the optimum illumination level from the standpoint of accident reduction. No study sections were available with higher illumination such as 2.0 or 2.5 HFC. The findings do not imply that such higher levels have utility, nor do they disprove the possibility.

If a relation exists between uniformity (either average or maximum to minimum), it was not identified in the research. The failure to find any relation is understandable in view of the illumination variations found along the subject routes.

EFFECT OF LATITUDE

The northern area routes tended to have high illumination values, and the southern routes had mixes of high and low levels. The southern locations were, therefore, examined separately. As a group, the lighted routes showed a better accident rate ratio than the unlighted (DeKalb County, Georgia) route. Also, those lighted sections with lower illumination had significantly better ratios than the lighted sections with higher levels. Thus, the presence of a geographic bias on the illumination levels has no apparent effect on the overall statistical findings based on data from both north and south locations.

COST-BENEFIT ANALYSIS

For the urban data as a whole, the average annual number of day accidents ranged from 12 to 160 per mile of 4-lane lighted freeway, with an average of 74. For 6-lane routes the range was 4 to 295, with an average of 52; for 8- and 10-lane routes, the range was 28 to 197, with an average of 89. These values have been used to compute the expected number of average night accidents for urban freeways with and without lighting. The average accident costs have been compared with estimated typical freeway lighting costs, including installation plus 20-year maintenance and energy cost projections. The calculations result in favorable cost-benefit ratios of 2.3 for lighting 4-lane urban freeway sections, 1.4 for 6-lane sections, and 1.7 for 8- or 10-lane sections.

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REFERENCE

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