STUDIES OF TRAFFIC SAFETY BENEFITS OF ROADWAY LIGHTING

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Numerous laboratory studies have been conducted to relate illumination levels and driver performance at night. Selected field studies have been made to relate the ability of drivers to recognize certain objects on the roadway under different illumination conditions. The latter studies have normally been of static conditions. The purposes of roadway lighting are to improve driver comfort and efficiency and to reduce accident frequencies. Studies have been made to correlate fixed roadway illumination and accidents, but the findings have not been entirely consistent for several reasons: inadequate sample sizes, lack of quality control on data collection, and inappropriate techniques of analysis. The purpose of this paper is to review some of the studies that have been made and some of the strengths and weaknesses of various study techniques.

•TWO GENERAL types of roadways have been studied: urban surface streets, which may be subdivided into major routes, collector streets, and local streets, and freeways, which may be characterized as urban, suburban, or rural.

Three kinds of accident studies have been performed: accident rates or frequencies on lighted roadways (at any illumination level) and on unlighted roadways of similar characteristics and effects on accident occurrence of different degrees of lighting, including illumination level or uniformity.

Special elements may be considered, such as frequencies of collision with lighting poles at various setback distances or by type of pole, i.e., rigid versus breakaway.

The effects of lighting as related to accidents may be analyzed by 2 general techniques. One is to use before-and-after data from a given segment of roadway. A number of such studies on similar types of roadways may be combined. The second method of comparison is the parallel type. In this analysis, accidents on comparable roadways (except for the lighting variable) are tabulated.

REVIEW OF PRIOR STUDIES

Principal studies of accidents on urban surface streets as related to lighting have been conducted by Seburn (1), Box (2), and De Leuw, Cather and Associates (7). Studies of freeway lighting, principally in urban and suburban areas, have been conducted by Huber and Tracey (3), Johnson and Tamburri (4), Box and Alroth (5), and Yates and Beatty (6).

Accident data may be presented as the percentage of total accidents that occur at night or as the night-day accident ratio, which is the number of accidents at night divided by the number during the day.

Alternate ways are the night accident rate, which is the number of accidents per million vehicle-miles (or per 100 million vehicle-miles) of travel, and the night-day rate ratio, which is the night mileage rate divided by the day mileage rate.

Table 1 gives the routes, methods of comparison, and accident sample sizes used in several major studies. The studies are discussed below.

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Kansas City

Seburn (1) reported results in the early stage of the Kansas City, Missouri, relighting program and used the ratio of day accidents to night accidents on a before-and-after basis. Another characteristic of those studies of major routes was the subclassification by volume groupings. At that time, the American Standard Practice for Roadway Lighting specified illumination level as a function of vehicular volume.

Subsequent studies by Box (2) used volume groupings but employed the percentage of total accidents occurring at night as the study method. His data also were subdivided by different illumination levels in order to determine whether this variable could be related to accident reduction as a result of relighting. A trend was noted, as given in Table 2 (15).

The data given in Table 2 are for 97 miles of streets relighted to conform with the then-recommended illumination levels. A change of 1 percent in accidents at night is equivalent to a 2 percent change in the accident frequency, when the effect of changes in the number of day accidents is also equated. On that basis, the data show that the relighting of major routes in Kansas City reduced overall property damage accidents about 4 percent, injury accidents about 18 percent, and fatal accidents about 28 percent. In 1966 the data were retabulated, based on the illumination levels provided in the relighting (8). Table 3 gives the percentage change for fatal and injury accidents during a 1-year period.

Box also used traffic counts at 122 locations on Kansas City streets to determine the average percentages of vehicle-miles driven at night. He found that total travel at night amounted to 26 percent on major streets and 24 percent on local residential streets. He postulated that, with that percentage of traffic at night, the expected conflicts with pedestrians would be much lower than during the day and that the percentage of pedestrian accidents at night, on properly lighted streets, should not exceed about 25 percent. Results from the Kansas City lighting program, which was initially addressed to the major streets where most night pedestrian accidents were occurring, verified this. By 1951 nearly half of the streets had been relighted. In the 6 years prior to that period, an average of 63 percent of pedestrian fatal accidents occurred at night. From 1951 through 1957, between 25 and 40 percent occurred at night; the average was 30 percent.

The Kansas City accident studies represent a simplified approach to analyzing the relation of lighting and accidents. From these and other studies, authorities have concluded that a serious night-accident problem may be assumed to exist when the ratio of night-day accidents is more than 1.5 times the average ratio for similar locations or sections on the same system of roads and streets (9). That language is part of a standard resulting from the Highway Safety Act of 1966.

Syracuse

The project in Syracuse (7) was planned to determine the type, priority, and amount of roadway lighting needed to reduce the ratio of nighttime to daytime vehicular and pedestrian accidents on the surface street system. A secondary purpose was to evaluate the economic impact on the city of upgrading street lighting to national standards.

The work included functional classification of the street network into major, collector, and local streets in accordance with the then-current edition of the American Standard Practice for Roadway Lighting (10). That work used prior classification planning studies, traffic volume data, and field surveys.

The types of development abutting the major and collector streets were determined from land use maps and field checks. Street widths were measured, and checks were made of the lighting system on a block-by-block basis. Separate sections were set up for each street segment where a change in width, illumination level, or functional classification occurred.

Accident data for 1 year were used, and the night-day accident ratio was computed for each segment. Those segments were then related by type of street and by illumination level. The night-day ratio of accidents was plotted as a function of maintained horizontal footcandles (HFC). From the curves, the optimum points of illumination were selected. In practically every case, worse ratios were produced by low and high illumination levels than by the intermediate level.

These optimum points were used for recommended changes in illumination of the city streets. A value of 1.8 HFC was determined to be the most favorable for major streets in downtown areas and intermediate areas. In outlying areas, a highly significant optimum point was not found, but a value of 0.8 HFC appeared to be appropriate. For collector streets as a group, the lowest accident ratio was found at an illumination level of about 1.0 HFC.

In the Syracuse study, a larger accident sample would have been desirable. Aside from that limitation, the type of approach appears to hold promise for future studies relating illumination levels and accident frequencies.

Connecticut Turnpike

As originally contemplated, a study was to be made of the effect of 3 different illumination levels on the Connecticut Turnpike (3). At the time of the study, the turnpike was lighted to a maintained level of approximately 0.6 HFC. A test section of 4.1 miles had illumination lowered to approximately 0.2 HFC. A second revision in the section, raising illumination to a level of 1.5 or 2.0 HFC, was not undertaken.

The lowered illumination in the test section was maintained for a 9-month period, during which only 36 night accidents occurred. Despite the fact that excellent control data were available from adjacent segments of the highway, the very small sample of night accidents in the test section did not produce any evidence that the illumination change had any effect on accident frequency.

Table 4 gives the accident data. In the test section, there was an apparent increase in the accident rate per million vehicle-miles. However, much larger increases were found in the control sections.

A more appropriate way of analyzing the data might be to use the night-day ratio of accident rates. On that basis, one could postulate an apparent improvement as a result of the lowered ratio during the test. However, the east control section showed a tremendous change in the night-day ratio, even though no change was made in the lighting. In the west section, where the sample of night accidents was more than 5 times greater during the test period and more than 3 times greater than that of the east section, little variation occurred in the night-day ratio. A more convincing demonstration of the importance of accident sample size could hardly be found.

The Connecticut Turnpike study demonstrates the value in calculating vehicle-miles of travel by day and by night and computing the night-day ratio of rates from those data.

Based on MVM data given in Table 4, about 27 percent of turnpike travel occurs at night. As will subsequently be shown, it is practical to calculate the ratio without MVM data if the percentage of night travel is known or can be estimated from other studies of comparable facilities.

Los Angeles

The Los Angeles study (4) was based on data on nonilluminated and illuminated freeways in the Los Angeles area. The study used the percentage of accidents at night and also the night-day accident ratio. The California researchers included dawn and dusk as part of night; with this questionable measure, they found approximately 30 percent of travel to occur during the night.

Maintaining that definition and recalculating the figures from the California study to relate them to the more generally accepted night-day ratio of accident rates per million vehicle-miles, we can determine a ratio of 1.58:1 for illuminated freeways and 1.85:1 for nonilluminated freeways.

The California work had an excellent data base. Although the researchers did not conclude that the differences in the day and night accident rate ratios were significant, the principles of their study are valid.

Another interesting technique they employed was to compare accident rates during the period of 5 to 7 p.m. in June, when it is daylight, with those during the same time period in December, when it is dark. An improved accident record was found on illuminated freeways as compared with the ones having no lighting. However, the sample sizes were quite small (on the lighted freeways during the 2-hour period, 34 accidents

Table 1. Characteristics of major accident-illumination studies.

Characteristic	Kansas City	Connecticut Turnpike	Los Angeles	IERI	Urban Interstate Highways	Syracuse
Types of routes						
Freeways		x	x	x	x	
Major routes	x					x
Collector streets						x
Methods of comparison						
Before-and-after	x	x		x		
Parallel type, lighted versus unlighted			x	x	x	x
Illumination level	x	x	x	x	x	x
Uniformity			x	x		x
Mehods of study						
Percentage of accidents at night	x					
Night-day ratio	x		x			x
VMT rates for selected hours					x	
Total night accidents		x		x		
Night-day ratio rates			x	x		
Number of accidents studied	8,700	2,640	17,170	21,400	Unknown	7,500

Table 2. Change in proportion of accidents at night on relighted streets in Kansas City.

			Before			After		
	Vehicles per			Night			Night	
Traffic	Hour	Accident Type	Day	Number	Percent	Day	Number	Percent
Light	150 to 500	Property damage	324	201	40	365	200	35
		Injury	47	45	49	57	34	37
		Fatality	3	3	50	2	1	33
Medium	500 to 1,200	Property damage	1,411	828	37	1,443	789	35
		Injury	172	210	55	152	135	47
		Fatality	10	17	63	6	5	45
Heavy	1,200 to 2,400	Property damage	547	323	37	672	340	34
		Injury	75	96	56	59	51	46
		Fatality	3	8	73	2	4	67
Total		Property damage	2,282	1,352	37	2,480	1,329	35
		Injury	294	351	54	268	220	45
		Fatality	16	28	64	10	10	50

Table 3. Fatal and injury accidents after major route relighting in Kansas City.

				Night Accidents					
Lighting Level	Route	Day Accidents		Before		After		Change	
(HFC)	Miles	Before	After	Number	Percent	Number	Percent	Number	Percent
0.2 to 0.39	38.7	80	99	67	46	86	46	+19	+28
0.4 to 0.59	40.8	126	99	173	58	82	45	-91	-52
0.6 to 0.79	7.2	45	23	43	49	23	50	-20	-47
0.8 to 0.89	5.9	31	36	72	70	28	44	-44	-61

Table 4. Accident rates on Connecticut Turnpike.

			Night			Day			Night-Day
Section	Route Miles	Time	Accidents	Million Vehicle-Miles	Rate	Accidents	Million Vehicle-Miles	Rate	Ratio Rate
West	27.6	Before	357	253	1.4	556	858	0.65	2.17
		During	204	97.3	2.09	304	331	0.91	2.28
Test	4.1	Before	79	43.7	1.80	167	179.7	0.93	1.93
		During	36	16.5	2.18	95	68.3	1.39	1.57
East	15.9	Before	82	83.8	0.98	263	346	0.76	1.30
		During	60	31.8	1.89	95	131.8	0.72	2.62

occurred in June and 41 in December). The technique may offer some promise, however, for application during a period of several years in areas having significant mileages of illuminated and of nonilluminated freeways.

IERI

A project sponsored by the Illuminating Engineering Research Institute (5) involved more than 200 miles of lighted and unlighted freeways; more than half the mileage was in urban or suburban areas. The study purpose was to relate night-day ratios of accident rates to varying illumination levels and uniformities. The study also provided before-and-after data for 2 freeway sections and data for both illuminated and nonilluminated sections of another freeway.

On many freeway sections, continuous hourly traffic data were available for 12-month periods. From light-meter readings at dusk and dawn, the researchers concluded that darkness (when the natural light level is only a few footcandles in value) ends about 15 min before sunrise and begins 15 min after sunset. Those data and traffic volumes, including interpolation of volumes during the dusk and dawn hours, were used to calculate night travel. Findings from Toronto, Chicago, Dallas, Atlanta, Denver, and Phoenix (including areas without daylight saving time) were that an average of 25 percent of annual night volumes can be expected on freeways in urban, suburban, and rural locations.

One of the aspects of the IERI study was the care taken in accident data tabulation. The researchers worked directly from accident reports in police files or from duplicate copies in files of traffic engineers in the various cities. The researchers separated the accidents occurring on ramps from those that occurred on the main line, at ramp entrances to the freeway, or at ramp exits from the freeway. They screened out accidents solely involving ramp connections to service streets because the illumination of the latter points is not necessarily representative of a given freeway illumination design. Furthermore, because of the possibilities of misfiling and miscoding, the most accurate method of tabulating accident data is to work from the accident reports themselves. This method also allowed comparison with outputs from computer systems. Errors ranging from 19 to 62 percent were found when data from the direct reports were compared with the printouts. Such differences in values could evidently mask lighting effects.

The IERI study found that lighted freeways had a night-day ratio of accident rates equal to 1.43. The unlighted freeway ratio average was 2.37. The net effect of lighting an urban freeway was concluded to be a 40 percent average reduction in night accidents. That is equivalent to an overall accident reduction of 18 percent (considering total day and night accidents). The apparent effect of freeway lighting on fatal and injury accidents represents a 52 percent reduction in night accidents.

The findings with respect to an "optimum" illumination level were similar to those of the Syracuse urban surface street study. The lowest ratio of night-day accident rates was found at a maintained illumination level of approximately 0.5 HFC. Based on the maintenance factors found at the various study sites, that value is equivalent to an initial illumination design of about 1.0 HFC.

In comparisons of lighted and unlighted sections of the same freeway and of before-and-after studies, the lighted freeway sections were found to have lower average ratios of night-day accident rates.

The freeway sections studied by IERI researchers had a very broad range of accident rates. Daytime rates varied from 0.39 to 9.24 accidents/MVM. Night rates ranged from 0.62 to 9.98 accidents/MVM. Such variations are typical of actual field conditions. To meaningfully study the effects of an element such as lighting, the researchers concluded that each section must be tested against itself. That cannot be accomplished by comparing night MVM accident rates among different freeways, but it can be done by calculating the ratio of night-day rates separately for each section and then comparing the ratios.

Urban Interstate Highways

A lighting study was performed as part of the Interstate System Accident Research, Study II (6). Data were furnished by various state highway agencies. The accident data were tabulated on an hourly basis; however, a tabulation of actual traffic volumes during only hours of darkness was not obtained. Presumably because of this, the research on night accident rates covered a period of consistent darkness (9 p.m. to 4 a.m.) for which traffic data were available.

The lighting portion of the Interstate accident studies was confined to the main-line freeway sections between interchanges in urban areas. The study concluded that "there is no discernible relationship between lighting intensity and accident rate on 2-lane or 3-lane main-line units." (This means 4-lane or 6-lane freeways.)

Although the data tabulation procedures for the Interstate study may be adequate for analysis of geometric design elements, some question can be raised as to their application to studies of lighting. To make a direct check, the Illinois Department of Transportation conducted a special study of accidents on several sections of Chicago freeways. Those sections duplicated ones that were analyzed in the IERI study, except that the Interstate Accident Study Procedure Manual was employed. To eliminate the data processing errors, the researchers worked directly from the same highway patrol accident reports on file with the department that were used in the IERI research.

Comparison of data from the 2 methods shows that only 60 percent of the total actual night accidents occurred from 9 p.m. to 4 a.m. Evidently, a reduction of that magnitude in the data base of the samples would have an adverse effect on statistical significance.

A comparison was also made of accidents tabulated on the main-line sections between interchanges, as contrasted with those in the interchange areas. In the IERI project, traffic engineers skilled in accident tabulation and analysis screened the accident reports. In the Illinois studies, lighting technicians were given instruction in reading accident reports, but they performed the actual tabulation without supervision of a traffic engineer. Differences would thus be expected in findings from the same data files. The differences ranged from 4 to 30 percent; the average was 13 percent. The traffic engineers found that a higher proportion (64 percent) of the accidents on the study section occurred on the main-line sections.

The Illinois study also compared the accident rate per million vehicle-miles at night and the 24-hour rate. In 2 sections on which before-and-after accident studies were performed, the differences found between the 2 methods ranged from 0 to 42 percent; the average was 16 percent. At one location, the change in the ratio of accident rates was 41 percent by the Interstate accident procedure and only 16 percent by the IERI procedure. On another section, the change in the ratio was 12 percent by the Interstate procedure and 33 percent by the IERI procedure.

A comparison of night accident rate computations per million vehicle-miles agreed on only 1 section. Differences as high as 33 percent were found in other sections; the average variation was 15 percent.

Those differences suggest that studies of accident effects, especially as related to items such as lighting, should be performed by experienced accident analysts. Furthermore, the use of straight rates per MVM in the basic, original Urban Interstate Highway Study technique, rather than the ratio of rates, runs head-on into the problem of widely varying accident rates due to traffic congestion and other elements not associated directly with lighting.

GENERAL DATA REQUIREMENTS FOR LIGHTING STUDIES

Accident Studies

The problems encountered and the successes achieved in various studies suggest that certain accident-tabulation factors are important. One aspect involves the location of the accident. That is needed to identify whether the collision actually occurred on the route under study or whether it involved a cross route having little or no relation to the basic analysis. The accident locations are also important to allow the subdividing of routes into sections having specific traffic or illumination characteristics.

A second element of accident tabulation concerns the date. Specific periods are sometimes needed because of partial-year periods involved in before-and-after analysis or to avoid periods of traffic disruption due to maintenance or reconstruction.

With respect to time-of-day tabulation, a simple "night" or "day" is usually sufficient. However, about 5 percent of the accidents may be found to occur in a dusk or dawn period. If those accidents are to be classified as either day or night, the time of accident is needed to the nearest 5 min. If hourly comparisons are to be made (as in the California studies), then the accident tabulation can be within clock hours.

Traffic Volumes

Box has shown that, if the percentage of traffic at night is known, it is unnecessary to secure vehicle mileage data in order to calculate the night-day ratio of accident rates on a mileage basis (5). The ratio is given by the following equation:

$$R = \frac{A_n (1 - P)}{A_d P}$$

where

R = ratio of night-day accident rate as a function of exposure,
A_n = number of night accidents,
A_d = number of day accidents, and
P = percentage of travel at night.

The findings on percentage of travel at night on urban surface streets in Kansas City and on freeways (Connecticut Turnpike plus the IERI study sites) are generally consistent. In another study on multilane major routes, Billion and Parson also found 25 percent of traffic mileage to occur at night (11). A study by Carroll, Carlson, and McDole on driving exposure of 7,145 persons throughout the country included information on day and night vehicle-miles (12). Interpolation of the data showed the calculated average percentage of travel at night to be 23 percent.

On the basis of those 5 studies, the application of a rounded value of 25 percent for night travel in urban areas (at least) appears warranted.

If it is desired to check or confirm the percentage of actual night traffic at a given location, hourly tabulations of volume are needed for a full 365 days. Those data are customarily taken from automatic recording stations along freeways. They should include the volume in both directions of travel. The calculation method, as reviewed in the IERI study, is as follows:

> The "dark" percentage of volume is separately calculated for the morning and evening dawn and dusk hour in which the threshold lighting condition (15 minutes before sunrise and 15 minutes after sunset) is reached. These percentages are applied as factors to interpolate volume during these two hours.
>
> The factored night volumes are added to the volume during the remaining hours of night traffic to obtain the total night volume of traffic. This value is then subtracted from the 24 hour total to secure the volume during the daylight hours. This procedure is repeated for each day of a full year, utilizing local sunrise/sunset tables and correcting as required for daylight saving time.

Selection of Study Sections

Each section of route should have relative stability during the entire study period. This includes no major change in traffic volumes, physical features, abutting land use, or illumination.

Reliable and accessible accident records are important, and their availability should be ascertained with respect to breakouts to conform with the selected study sections. Similarly, if traffic volume calculations are to be made, accessibility of counts must be verified.

If variations in illumination are to be compared, they should be considered when field measurements are taken of the existing illumination. This can be done in almost any conditions. In the IERI study, illumination was measured on a point-by-point grid method on freeways having as many as 10 lanes and under live traffic conditions. They were generally taken between 2 and 4 a.m.

Study Period

To secure comparable data requires that the seasons be similar. Data from the given months of one year must be compared with data from the same months of another year in most types of studies. An exception is the peak-hour winter versus summer study done in California.

In before-and-after studies, a sufficiently large total number of accidents must be tabulated to reach statistical significance. One measure of this could be the employment of Poisson and chi-square curves as given by Michaels (13). The Poisson curve is recommended by Michaels for use to minimize the chance of calling a reduction not significant when it actually is. At the other end of the scale, the chi-square curve is used to minimize the chance of calling a reduction significant when it actually is not. To illustrate the application of those curves, two hypothetical findings, based on before-and-after accident studies, may be considered. In the case of illumination analysis, it would be appropriate to use only the night accidents. If, for example, 40 accidents occurred at night with a given condition of lighting, a reduction of 25 percent (30 accidents in the after period) would be essential to justify a conclusion that an actual reduction and not chance had taken place. However, a reduction of as much as 40 percent (24 accidents in the after period) would be needed to reach a high level of statistical significance.

By comparison, a sample of 100 night accidents in the before period would require a reduction of only 18 percent to achieve probable significance, and a reduction of not more than 25 percent would be required to meet the more stringent chi-square test. If 200 accidents are involved in the before night sample, then a reduction of only 13 to 19 percent would be significant.

There is no such thing as a statistical guarantee of significance. The extreme variabilities in accident occurrence produced by chance alone may well hide the benefits of an improvement. Conversely, a chance reduction in accidents can cause an unwary researcher to conclude that he has improved a situation when, in fact, his changes have produced no meaningful results. The development of well-controlled accident analysis techniques is currently the subject of an NCHRP project (14). Meanwhile, the application of simple techniques such as that presented by Michaels, coupled with common sense and care in data tabulation, will greatly aid the researcher.

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