CONTINUOUS FREEWAY ILLUMINATION AND ACCIDENTS ON A SECTION OF RTE. I-95

by

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(The opinions, findings, and conclusions expressed in this report are those of the author and not necessarily those of the sponsoring agencies.)

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SUMMARY

Beginning with the oil embargo of 1973-74, highway lighting — and particularly continuous lighting on freeways — became one of the first items to be cut back to conserve energy and revenue. During this period of energy shortage, considerable lighting was turned off in Virginia and in particular the 13.8 km (8.57 mi) section of continuous lighting on I-95 between Springfield and Washington, D. C. By comparing the accident rate ratios for the lights turned off with those for the lights turned on it was found, in an earlier study, that the lighting decreased the night accident rate on this section of I-95 during the three-month period studied. Subsequently, the lights were reactivated. The study reported here extended the data to cover a six-month period and used a more refined approach in the analysis.

For the period including December, January, and February, when heavy traffic volumes are on the I-95 roadway during the early hours of darkness, the lighting was found to be particularly effective in reducing the nighttime accident rate. For the March, April, and May period, when the hours of daylight lengthen, the night accident rate was improved; but the improvement was not found to be significant at the 95% confidence level, due, most likely, to the low number of accidents involved in the test. For the overall six-month period it was concluded that the lighting reduced the night accident rate. This finding was significant at the 95% confidence level. Evaluation of the night-to-day accident rate ratios on an unlit control section of I-95 substantiated this finding.

It was recommended that any plans for reducing energy consumption by turning off entire sections of freeway lighting should be carefully considered for possible adverse effects on the nighttime accident rate.

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INTRODUCTION

It has been well established that nighttime driving is more hazardous than daytime driving. Accident statistics for recent years have shown that the nighttime highway accident rate is two or more times the daytime rate.[1,2] While a number of factors such as headlight glare, driver fatigue, intoxication, and, possibly, the greater prevalence of reckless drivers contribute to the higher nighttime accident rate, visibility is the major variable in the two general driving conditions.

Street lighting has been used in urban areas to help reduce the crime and accident rates, and more recently continuous lighting has been used on freeways where traffic volumes, interchanges, peripheral lighting adjacent to the roadway, and other factors tend to warrant its use. Except in very unusual situations, however, continuous lighting on freeways does not contribute to a reduction in the crime rate, a reduction in intersection accidents (since there are no at-grade intersections), nor a reduction in accidents involving pedestrians as does lighting on urban streets. Therefore, to be effective from an operational viewpoint continuous lighting on freeways should improve general nighttime traffic operations and reduce the nighttime accident rate.

Although continuous lighting has now been used on freeways in various locations in this country for a number of years, there is still considerable doubt concerning its effectiveness. The initial costs of the lighting installations plus the subsequent costs for energy and maintenance cause considerable concern about the potential benefits that may be derived from these investments. Higher energy costs, coupled with the likelihood that these costs will continue to increase, have served to intensify concern in some quarters regarding the effectiveness of continuous lighting in reducing the nighttime accident rate. Therefore, evaluations of existing lighting installations are desirable to provide information that can be used to establish priorities for future lighting and for possible reductions in existing lighting in the event of future energy shortages and revenue shortfalls.

In some studies that will be reviewed in more detail later, there has been a lack of data substantiating that continuous freeway lighting enhances safety. Much of the difficulty in analyzing accident data, for example, has resulted from the lack of comparable data for before and after lighting situations on the same sections of roadway. Other studies, which will also be reviewed briefly, have indicated that continuous freeway lighting does provide improvements in safety by reducing the nighttime accident rate. A study of three months of accident data both with and without continuous lighting on a 13.8 km (8.57 mi) section of I-95 (Shirley Highway) in Virginia indicated that lighting was beneficial in reducing the nighttime accident rate.[3] That study was made possible by the fact that the lighting was reduced due to the energy crisis resulting from the oil embargo in 1973-74. Since that initial study covered only three months of comparative accident data, the decision was made to extend the study to cover most of the period during which the lighting was reduced.

The lighting was reduced for approximately six months. The earlier study, however, covered only the accident data available at that time, which were for the winter period of 73-74 when the hours of darkness were at a peak. Therefore, the extended study, which is the subject of this report, was to examine possible seasonal effects that may have had a bearing on the earlier results. While six months of comparative before and after accident data provide only a limited quantity of information for statistical evaluations, this limitation could not be avoided because of the reactivation of the lighting with the easing of the energy shortage.

RESULTS OF SOME PRIOR STUDIES

Relative to the number of vehicle miles of travel on our highways, accidents occur infrequently. Because of the numerous variables that can be associated with highway accidents, therefore, it is desirable to obtain a large quantity of data to enhance the statistical significance of the results. Since the quantity of accident data available for the present study was somewhat limited, it is desirable to review some earlier studies relating to roadway illumination and accidents so that the results of this study can be viewed in perspective.

In reviewing the relationship of accident rates to roadway illumination, the differences between street lighting, regular highway lighting, intersection lighting, and freeway lighting must be recognized. The last mentioned type of lighting is considerably different from the other three types in that at-grade intersections, stopping or turning traffic, and pedestrians are factors that are not normally encountered on freeways.

Street Lighting

Numerous studies have shown that lighting reduces the nighttime accident rate on streets. A 1957 Highway Research Board publication, for example, concluded that there is a definite tendency for increased average levels of illumination to reduce the nighttime accident rate.(4) Even earlier, in the 1930s, the night-to-day fatality rate was found to have doubled in one city when lighting was reduced.(5) A more recent report, one issued in 1969, indicated that the existing street and roadway lighting in the Washington, D. C., metropolitan area is saving motorists $15 million in direct accident costs per year.(6)

Foreign experience with street lighting has been equally as impressive. In the United Kingdom a study of 64 locations where lighting conditions had been improved revealed a 30% reduction in night casualty accidents and a 45% reduction in accidents involving pedestrians.(7) Sixty-five miles of streets in metropolitan Sydney, Australia, were studied over a four-year period after improved lighting was installed and a 25% reduction in casualty accidents and a 57% reduction in pedestrian casualties were reported.(8) It was estimated that $1.89 million in accident costs were avoided during a two-year period while the costs of the lighting was $503,000.

In a recent study conducted in the Philadelphia metropolitan area it was found that increased visibility levels decreased the accident rate.(9,10) Thus, for many years research has shown that street lighting is very effective in reducing nighttime accident rates.

Intersection Lighting

Lipinski et al. have reported on a review of many articles regarding roadway illumination on rural at-grade intersections written prior to 1969.(11) From those articles reviewed that pertained to accident reduction, it was concluded that the effectiveness of lighting in improving safety at intersections was no longer debatable. From accident data representing many states and cities, a curve has been developed that gives an average percentage reduction in accidents achieved by lighting an interchange.(12) These data clearly show that a reduction in intersection accidents can be expected after the improvement of lighting.

General Highway Lighting

It is often difficult to distinguish between street lighting and highway lighting since many suburban highways with heavy development along the right-of-way have the same general characteristics as urban streets. Nevertheless, many studies have shown that highway lighting is highly effective in reducing the nighttime accident rate. A study in Indiana of before and after lighting,[13] for example, indicated that the cost savings from reductions in accidents were greater than the costs of certain lighting programs. Another study showed a reduction of 22% in accidents and 39% in injuries per million vehicle miles of travel after the installation of lighting.[14] In a much earlier study conducted in New Jersey during the 1930s, it was concluded that where adequate highway lighting was provided there was a substantial reduction in night accidents.[15] A number of additional U. S. studies like those cited above have concluded that roadway lighting reduces the rate and severity of nighttime accidents.

Results in other countries have been equally as good, or better than those reported in the U. S. In the United Kingdom, for example the installation of good lighting on rural two-lane roads reduced night casualty accidents by 48%. On dual-lane roads, good lighting reduced night accidents by 38%.[16] In Belgium, a one-year study of all accidents on 1,300 km (808 mi) of roads in rural areas concluded that effective lighting could reduce the night accident rate by 20%.[17] So, it is apparent that roadway illumination is effective in reducing the accident rate on rural highways.

Freeway Lighting

On limited access freeways, the effectiveness of roadway lighting in reducing the night accident rate has often been questioned. Some of the earlier studies of freeway lighting installations were either inconclusive or suggested little or no difference between the accident experiences on lighted and unlighted roadways. Conflicting conclusions were demonstrated when in 1966 a joint Institute of Traffic Engineers — Illuminating Engineering Society Committee reported on a study of 12 freeways and concluded that the night-to-day accident ratio was lower on facilities with higher and more uniform levels of illumination;[18] then, in 1967, the American Association of State Highway Officials concluded that the need for continuous roadway lighting could not be fully supported on the basis of accident experience or traffic operations.[19] Conflicting committee reports such as these are understandable in view of the results of some specific studies reviewed below.

A California study reported in 1965 concluded that continuous, low level illumination ranging from 2.2 to 3.8 lux (lx) (0.20 to 0.35 footcandles [fc]) was of little or no benefit in reducing accidents.[20] It was acknowledged, however, that the results might be due to the study methods used since the average levels of illumination were considerably below the 6.5 lx (0.6 fc) recommended for freeways by the AASHTO.[21] Further review of the report on this study suggests that the light poles themselves were involved in many fixed object accidents — particularly at night. (An earlier California study had reported that approximately 3% of fatal freeway accidents involved light poles.[22]) In addition, this study was based on a comparison of different illuminated and nonilluminated freeways rather than the more desirable before and after analysis of the same freeway. The most meaningful results of this particular study possibly could have been a comparison of the accident rates during the daylight period of 5 p.m. to 7 p.m. in June with those of a like period of time in December when it is dark. In this comparison of illuminated and nonilluminated freeways an improved accident record was found, but the sample size was small, as might be expected.

In a study conducted on the Connecticut turnpike the lighting intensity was reduced from 6.5 to 2.2 lx (0.6 to 0.2 fc) on a 6.6 km (4.1 mi) test section. The night accident rate increased when the lighting intensity was reduced but the reduction was not found to be statistically significant when tested against the rates for control sections of roadway.[23] Still another study of interstate system accidents, reported by Yates and Beatty,[24] concluded that the accident rate between interchanges was higher on lighted than on unlighted roadways, regardless of whether the freeway was 4-lane or 6-lane. This study, however, considered only the accidents occurring between 9:00 p.m. and 4:00 a.m. Using a more exacting procedure to distinguish between night and day accidents, Stark reported that only 60% of the total night accidents occurred between 9 p.m. and 4 a.m. on several sections of Chicago freeways.[25] He concluded that a reduction in the data base of that magnitude would certainly have an adverse effect on the statistical significance of the results. In further evaluation of that study and the Connecticut study, the desirability of calculating the night-to-day ratio of accident rates was stressed. This technique was further applied to the California study cited earlier. Thus, by proportioning the day-to-night accident rate ratios to the millions of vehicle miles of travel (MVMT) on each of the three illuminated freeways analyzed in the California study, and by expressing the ratio in the more generally accepted night-to-day form, values of 1.58:1 and 1.85:1 were obtained, respectively, for illuminated and nonilluminated freeways. These results suggest that on an MVMT basis the provision of illumination on freeways might be more effective in reducing accidents than originally suspected.

Some of the limitations of studies like those cited have been recognized. Generally, the unavailability of situations where sufficient before and after studies could be conducted, the lack of adequate or desirable lighting levels, the lack of guardrail or other protection to prevent collisions with light poles in many early installations, and limited accident and traffic data have all served to make adequate analyses and interpretation of the results extremely difficult.

Contrasting with the general results of the studies reviewed above, a 39% reduction in all types of night accidents was reported in France after lighting was installed on a 4.5 km (2.8 mi) section of freeway.(26) On a section of the M4 motorway in the United Kingdom the installation of lighting reduced accidents by 38%, the number of injury accidents by 5%, and the number of casualties by 15%.(27)

The most comprehensive study of freeway lighting was reported in 1971 by Box.(28,29) This work, which is usually referred to as the IERI (Illuminating Engineering Research Institute) Study, included 326.7 km (203 mi) of routes which experienced more than 21,000 accidents during the selected study periods. The areas represented in the study included Denver, Chicago, Atlanta, Dallas, Phoenix, and Toronto. Most of the routes were 6-lane freeways in urban or suburban areas. For the most part, the study involved a comparison of illuminated and nonilluminated freeways. Two sections, 3.4 and 5.2 km (2.1 and 3.2 mi) in length, of the I-94 Calumet freeway in Chicago, however, were studied by the before and after method. A third method of comparing lighted versus unlighted sections of the same route was also used in the study.

As a group, all the lighted freeways studied had an average night/day accident rate ratio of 1.43:1 whereas the unlighted freeway average was 2.37:1. These data were used to determine that an average reduction of 40% in night accidents, or an overall accident reduction of 18%, can be obtained with freeway lighting.

The results of the before and after study on the two sections of I-94 in Chicago are given in Tables 1 and 2. The night-to-day ratio, which is explained in more detail later, was lower on each section after the lighting was installed. Statistical evaluations of the accident data indicated that the lighting installations had quite possibly lowered the night accident rate, but the author felt that an exhaustive statistical confirmation was lacking for these two roadway sections. All three of the comparison methods, however, indicated that the lighted freeways had lower accident rates than did the unlighted freeways.

Table 1

Before and After Lighting Study
Calumet Freeway, 132nd to 146th Street
(Taken from reference 28)

Number of Accidents Per Year	Before	After
Injury-Fatal		
Day	15	17
Night	23	10
Total	38	27
All Accidents		
Day	40	29
Night	46	14
Total	86	43
Percent Accidents at Night		
Injury-Fatal	61%	37%
All Accidents	53%	32%
Accident Rate Per MVMT		
Day	1.06	1.18
Night	3.19	1.59
Overall	1.59	1.29
Night/day ratio	3.0:1	1.3:1

Table 2

Before and After Lighting Study
Calumet Freeway, 146th to 167th Street
(Taken from reference 28)

Number of Accidents Per Year	Before	After
Injury-Fatal		
Day	15	30
Night	26	20
Total	41	50
All Accidents		
Day	50	76
Night	52	51
Total	102	127
Percent Accidents at Night		
Injury-Fatal	63%	40%
All Accidents	51%	40%
Accident Rate Per MVMT		
Day	1.30	1.73
Night	3.96	3.40
Overall	1.96	2.15
Night/day ratio	3.1:1	2.0:1

Other findings from the study by Box indicated that the freeways with in-service illumination levels between 3.2 and 6.5 horizontal lx (0.3 and 0.6 horizontal fc) had the most favorable accident rate ratios. For drivers age 40 and above, there was a substantial reduction in accidents on the lighted sections of freeway. In addition, it was found that areas between interchanges tended to have higher percentages of accidents at night than did areas within the interchanges.

VIRGINIA I-95 STUDY

General Description of Roadway Lighting

The continuous roadway lighting on I-95 begins on the south side of the Potomac River across from Washington, D. C. It extends from the area near the Pentagon southward to a point just south of the Springfield interchange (Figure 1). Most of this section of roadway lies between Washington and the Rte. I-495 Washington circumferential interchange just north of Springfield. The entire section covers a distance of approximately 16 km (10 mi). The accident study, however, was confined to the approximate 13.8 km (8.57 mi) southerly portion.

A general cross section of the Rte. I-95 roadway consists of 8-10 lanes. Six or 8 of the lanes, as the case may be, serve north- and southbound traffic, and 2 are reversible lanes in the center of the roadway. Nine interchange areas are located within the length of the lighted section of roadway, and each is quite different in geometric design. Therefore, there are a variety of lighting situations in the interchange areas. The lighting along the main line of the highway, however, is provided by 1,000-watt mercury luminaires mounted at a height of 15.2 meters (50 ft) on 3.7-meter (12-ft) mast arms. The lamp posts for the luminaires are positioned on the shoulders of the roadway and provide lighting for the reversible lanes as well as for the regular traffic lanes. A typical view of the luminaires and roadway section is shown in Figure 2, where it can be noted that all light poles are positioned behind the guardrail.

Because of the various geometric configurations at the interchanges, the locations of the luminaires on the main line in these areas vary from the general layout described above. Typical sections and illumination data for the various general lighting situations on the main line and some interchange ramps were shown and discussed in earlier reports.[30,31] The studies conducted on the main line roadway have shown that the average maintained levels of illumination and uniformity are well within the recommended standards for freeways.[31

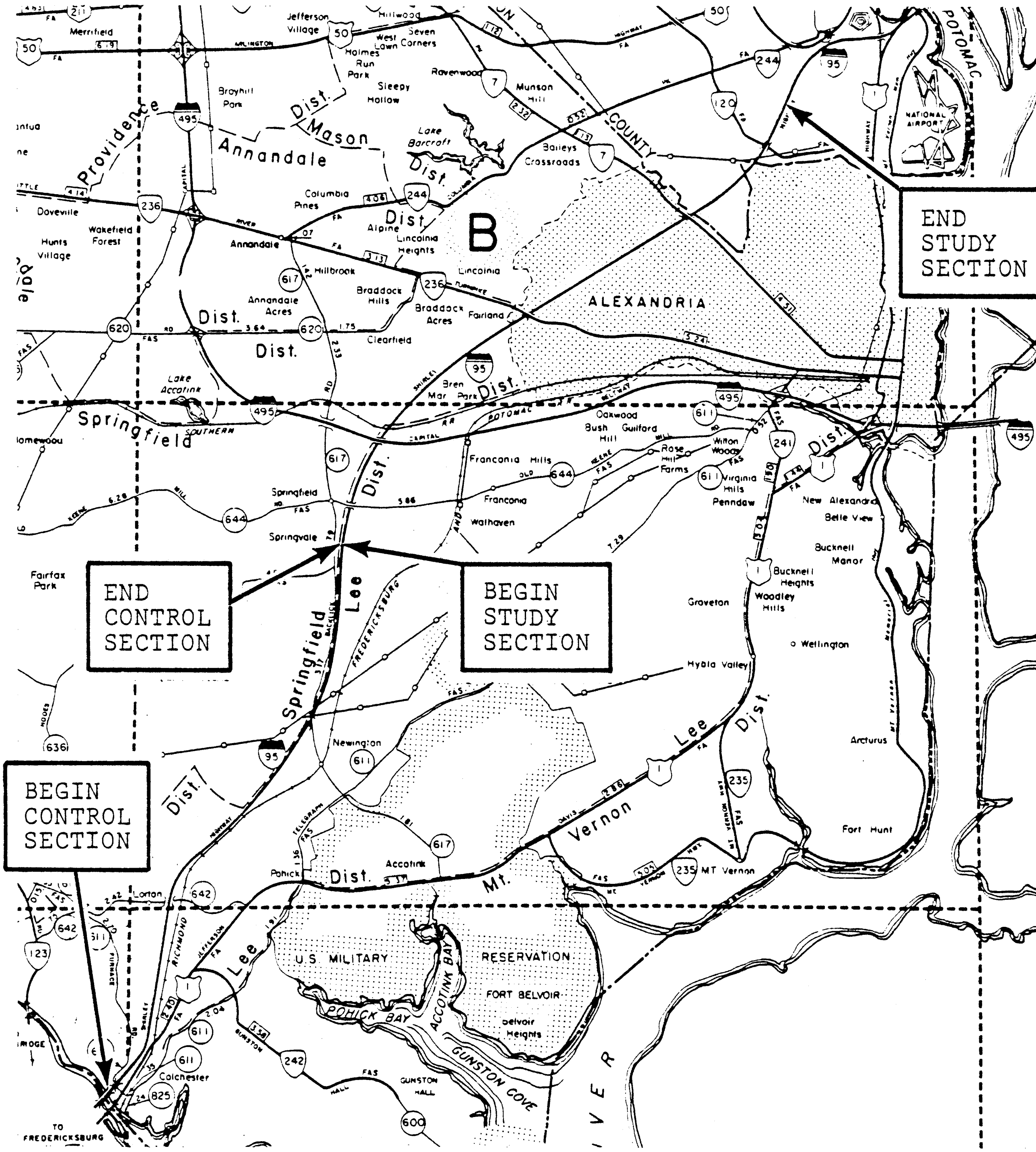

Figure 1. Section of roadway studied.

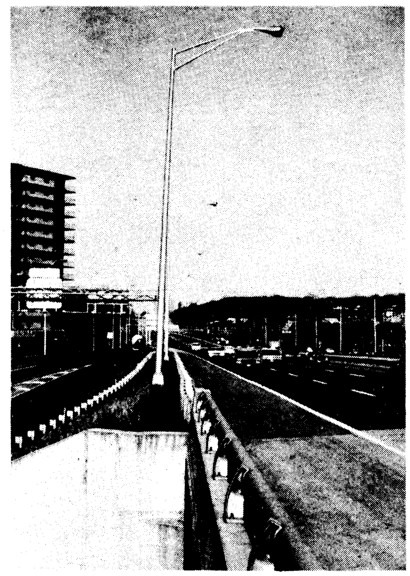

Figure 2. Typical view of luminaires on Rte. I-95, looking north from the Glebe Road interchange area.

Purpose and Scope

In the decision to use continuous lighting on the Shirley Highway, the peak traffic volumes during the early morning and evening hours of darkness in the fall and winter months was a consideration. The incorporation of the reversible lanes in the design was an additional factor, because the lighting would be of benefit when clearing the roadway of vehicles involved in nighttime accidents and would provide light for surveillance systems if operational problems required their use. While a surveillance system has not been used to date, the expectation that the lighting would be the most effective in reducing nighttime accidents during the peak traffic volume hours still appears valid. As stated earlier, a report covering an analysis of three months of accident data for the winter of 1973-74 indicated that this expectation was being realized. The main purpose of the extended study reported, therefore, was to reanalyze the accident and traffic data to include a 6-month period (the approximate length of time that the lights were turned off) during the energy crisis of 1973-74. The scope of the study was limited to the period from December 2, 1973, to May 31, 1974, during which the lighting was turned off between interchanges as compared with a like period of time the previous year when the lighting was operational.

General Data Analysis

Traffic accident data can be presented in several ways, but in the case of before and after changes involving highway lighting, the use of night-to-day accident rate ratios has evolved as the generally accepted method of evaluation. The day or night accident rate is the number of accidents per million (or hundred million) vehicle miles of travel during day or during night. The night-to-day accident rate ratio is the night rate divided by the day rate. In studying the effects of lighting, therefore, a comparison of this ratio for a roadway without lighting with the same ratio for the roadway lighted will yield meaningful results. It is important that the comparison be made on the same section of roadway so that factors such as geometrics and traffic flow characteristics not associated with lighting will be the same in each case.

Traffic Count Data

To obtain the accident rates for both day and night the traffic count data must be adjusted to the constantly changing hours of darkness. Since the traffic count data obtained during the study period were recorded hourly from 7 a.m. to 7 p.m. for day and from 7 p.m. to 7 a.m. for night, the hourly counts were proportioned to the actual hours of darkness and adjustments in the night and day volumes were made accordingly. In the earlier report,(3) these adjustments in traffic volumes were made for the shortest and longest days during the 3-month study period as based on the times of sunrise and sunset. Artificial light, however, is not normally needed at the exact time of sunrise or sunset. In studies conducted in the Chicago area by Box,(28) the decay in lighting after sunset and its buildup before sunrise were measured during the months of January, April, and July. Utilizing these data, it was determined that a good estimation of the threshold point (when natural lighting approaches a level where artificial lighting becomes a significant added factor in driver visibility) would be 15 minutes before sunrise and 15 minutes after sunset. This refinement was used to distinguish between night traffic volumes and day volumes in the data analysis. Therefore, the rates reported in the earlier 3-month study will differ from those reported here.

The decision to turn off the lighting was related to the energy problem existing at that time and the study of the accident data was not a planned operation. Accordingly, the nighttime traffic count data taken during the period are limited to those from routine observations at one key station near the north central portion of the study section. Twenty-four hour traffic count data obtained subsequent to the period of reduced lighting were reviewed to determine the relative difference between weekend and weekday traffic volumes. In addition, data for five additional daytime traffic count stations located within the study section were reviewed and compared to the daytime counts obtained at the key nighttime count station. Although there were some expected variations between stations, the average daytime traffic for all the stations was within approximately 2% of that reported at the key station.

The use of the average traffic volume data for the study section during the before and after periods would, at any rate, be the only practical approach to the problem, primarily because the total number of accidents during the periods was not great enough to lend significance to a more refined analysis for smaller sections of roadway such as those between interchanges.

The adjustment of the day and night traffic count data to 15 minutes prior to sunrise and 15 minutes after sunset had the net effect of decreasing the night traffic counts and increasing the day counts during the longer daylight periods.

Accident Rates

Since the traffic count data obtained at the key station were found to agree very closely with the average counts obtained from all other stations within the study section, the accident rates were calculated based on these representative average traffic volume data. Since the night and day traffic volumes varied on weekends as opposed to weekdays, special continuous counts were taken over the weekends at three times of the year. The average weekday, Saturday, and Sunday volumes were proportioned to determine composite average traffic volumes for daylight and darkness. Finally, the accident rates were calculated based on traffic volumes for the average length of daylight and the average length of darkness during each three-month study period.

Results

Accident Data

The accident data for the study section are summarized in Table 3 for comparable periods of time with the lighting on and with the lighting off. The data are broken down for the two three-month periods and totaled for the entire six-month comparative period for each lighting condition. For the "lighting off" period, there was a decrease in the number of accidents during both the day and night. For the first three-month comparative period, daytime accidents were 42.0% less and night accidents 10.5% less when the lighting was off than when on. This might appear to suggest that turning off the lighting reduces the number of night accidents.

Table 3

Summary of I-95 Accidents with Lighting On and Lighting Off

Months	No. of Days	Number of Accidents				All Accidents	Acc. Severity		
		Daylight	Night	Dawn	Dusk		Prop. Damage	Injury	Fatal
LIGHTING ON (1972-73)									
Dec., Jan., Feb.	89	74	57	6	11	148			
Mar., Apr., May	92	112	49	4	7	172			
TOTALS	181	186	106	10	18	320	256	64	0
LIGHTING OFF (1973-74)									
Dec., Jan., Feb.	89	43	51	10	3	107			
Mar., Apr. May	92	61	20	2	0	83			
TOTALS	181	104	71	12	3	190	137	52	1

Further consideration, however, would suggest that the percentage decrease in night accidents during the "lights off" period should be roughly the same as that occurring for the day conditions. These statistics alone are a good example of the importance of expressing the data in terms of the ratio of night-to-day accident rates with lighting as opposed to the same type ratio without lighting.

For the second three-month period there were 46% fewer accidents during the day and 59% fewer during the night when the lights were off. For the full six months there were 44% fewer daytime and 33% fewer nighttime accidents when the lights were off. While there was a substantial reduction in the number of accidents during the "lighting off" period, injury accidents decreased by only 19% and fatalities increased. Fortunately, only one fatality was involved in all of the accidents for the combined study periods.

Traffic Volumes

Traffic volumes during the study periods were determined as described earlier and are summarized in Table 4. A more vivid illustration of the constantly changing day and night traffic volumes in the I-95 study is shown in Figure 3. The data presented in Figure 3 are pre-energy crisis weekday and weeknight traffic volumes for the December 1972 to June 1973 period.

Table 4

Summary of Average Traffic Volumes on I-95
During the Study Period

Months	No. of Days	Traffic Volumes			
		Average Weekday	Average Weeknight	Average Composite Day	Average Composite Night
LIGHTING ON					
Dec., Jan., Feb.	89	60,732	34,847	56,524	34,715
Mar., Apr., May	92	76,216	24,301	68,976	26,388
LIGHTING OFF					
Dec., Jan., Feb.	89	63,915	31,584	59,551	31,465
Mar., Apr., May	92	88,518	18,981	80,105	20,611

In developing the data shown, regular average hourly traffic counts were adjusted to 15 minutes before the time of sunrise and 15 minutes after the time of sunset for the Washington, D. C., area. It can be noted that during December and January, when the hours of daylight are the shortest, the volume of traffic during darkness is not greatly different from that during daylight. Approximately 44% of the total traffic volume occurs during the hours of darkness for that particular period. By way of contrast, only 16% of the total traffic volume was on the roadway during the shorter hours of darkness in June.

Comparing the "lighting on" with the "lighting off" traffic volumes given in Table 4, it can be noted that the night traffic volumes decreased during the period the lights were off. This probably is a result of reduced driving after working hours caused by the shortage of gasoline. To some degree this fact explains the overall reduction in the number of accidents during the energy crisis. It is likely, however, that the concurrent reduction in the speed limit to 88 km/h (55 mph) played a significant role in the lower overall accident experience during the "lights off" study period. Nevertheless, the lower traffic volumes during darkness in the March, April, and May energy crisis months would significantly lower the opportunities for accidents and perhaps explain the relatively low number of night accidents during that period.

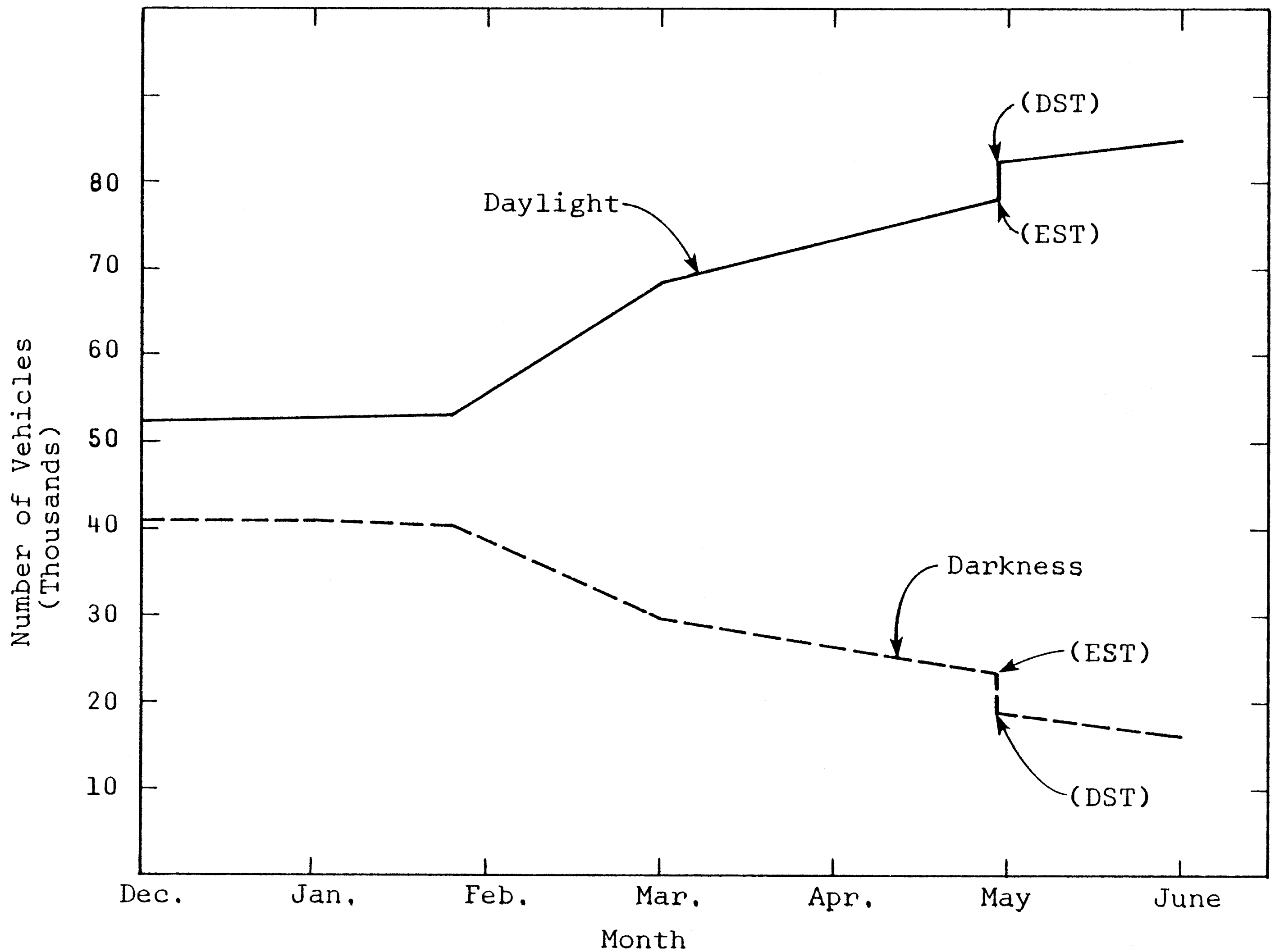

Figure 3. Typical average weekday and weeknight traffic volumes on the I-95 study section. (Day and night traffic volumes adjusted to 15 min. before sunrise and 15 min. after sunset.)

As opposed to the typical weekday and weeknight, the weekend traffic volumes differ somewhat, as shown in Figure 4. While the average Saturday daytime volume does not differ markedly from that for the average weekday, the Sunday daytime volume is considerably lower. In addition, the night traffic volumes do not appear to vary as much over the seasons as do the weekly volumes. This may be a reflection of the greater night travel during weekends — particularly during the spring and summer tourist seasons.

In order to adjust the overall average traffic volumes to account for the weekend differences, the counts were proportioned based on the number of Saturdays, Sundays, and weekdays in each study period. The resulting data are reported as average composite day and average composite night traffic volumes in Table 4.

Accident Rates and Rate Ratios

The day and night accident rates for each study period were calculated by standard procedures based on the average composite traffic volumes and are given in Table 5. These data indicate a marked decrease in the daytime accident rate during the "lights off" period. A corresponding decrease in the night rate does not occur except during the March through May comparative period.

Accidents occurring during dawn and dusk are difficult to deal with in a study of the effects of illumination. It is probably best to exclude them entirely; but, in many instances it is likely that lighting would improve visibility during these transitional periods. Therefore, the dawn and dusk accidents were included with the night accidents and an additional set of rates calculated. This resulted in higher accident rates, which are also given in Table 5.

The calculated night-to-day accident rate ratios are presented in Tables 6 and 7. Considering only the night accidents, the accident rate ratios were lower for each three-month study period and for the total six months when the lighting was on (Table 6). Reductions in the accident rate ratios range from 44% for the December through February period when the night traffic volumes were the highest to 10% during the March through May period when the night traffic volumes were rapidly decreasing. For the entire six-month period there was a 36% reduction in the rate ratios with the lighting on. By including the dawn and dusk accidents with the night accidents, the reductions in the rate ratios were respectively 42%, 0%, and 33%, as shown in Table 7. These compare favorably with the general 40% reduction reported by Box and with his data shown earlier in Tables 1 and 2 for before and after analyses on the same roadway sections. It should be noted that the six-month statistics shown in Tables 6 and 7 are not an average of the two three-month periods, but were calculated independently using the accident data and average composite traffic volumes for the entire six months.

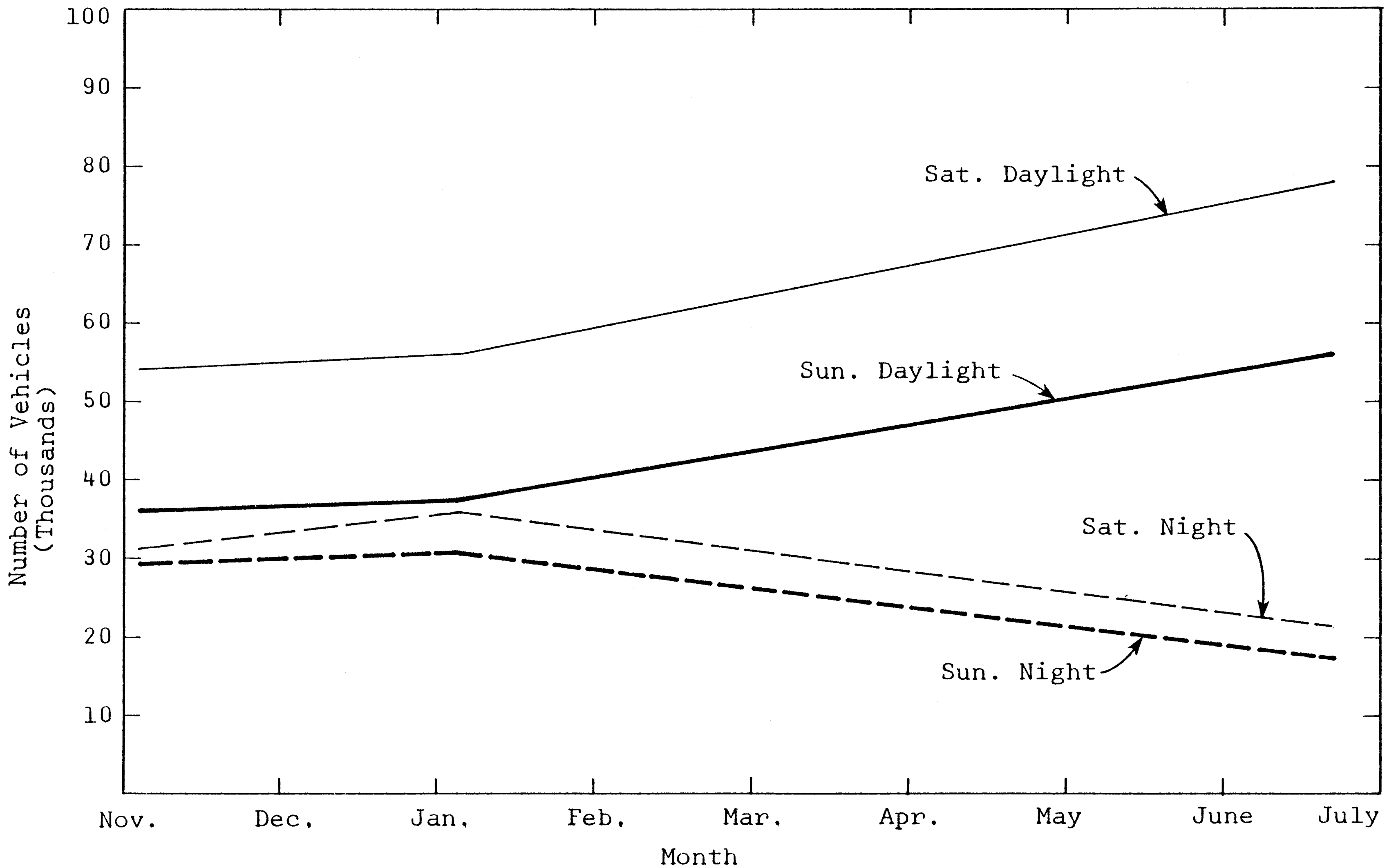

Figure 4. Typical average weekend day and weekend night traffic volumes on the I-95 study section. (Day and night volumes adjusted to 15 min. before sunrise and 15 min. after sunset.)

Table 5

Day and Night Accident Rates With
Lighting On and Lighting Off

Months	No. of Days	Day	Night	Night (including Dawn & Dusk)
LIGHTS ON (1972-73)				
Dec., Jan., Feb.	89	171.46	215.27	279.48
Mar., Apr., May	92	205.96	235.57	288.39
Dec., Jan., Feb., Mar., Apr., May	181	191.00	223.67	282.75
LIGHTS OFF (1973-74)				
Dec., Jan., Feb.	89	94.67	212.51	266.68
Mar., Apr., May	92	96.58	123.07	135.38
Dec., Jan., Feb., Mar., Apr., May	181	96.01	175.79	212.93

NOTE: Based on average composite daily traffic volumes. Rates per 100 MVMT.

Table 6

Night-to-Day Accident Rate Ratios

Month	Lighting On	Lighting Off	Percent Reduction	Significant at 95% Level
Dec., Jan., Feb.	1.26:1	2.25:1	44	Yes
Mar., Apr., May	1.14:1	1.27:1	10	No
Dec., Jan., Feb., Mar., Apr., May	1.17:1	1.83:1	36	Yes

Table 7

Night-(Including Dawn and Dusk)-to-Day Accident Rate Ratios

Month	Lighting On	Lighting Off	Percent Reduction	Significant at 95% Level
Dec., Jan., Feb.	1.63:1	2.82:1	42	Yes
Mar., Apr., May	1.40:1	1.40:1	0	No
Dec., Jan., Feb., Mar., Apr., May	1.48:1	2.22:1	33	Yes

Testing for Significance

The data in Table 6 indicate that for each three-month period and for the total six months, lower night-to-day accident rate ratios occurred when the roadway lighting was on. The question is, Were the lower, more favorable, accident rate ratios due to anything more than chance? Michaels reported two simple relationships for determining the significance of a percentage reduction in accidents.[32] Two curves, which represent two limits, were developed to test for significant reductions in accidents. The first can be used to minimize the chance of calling a reduction not significant when in fact it is. This curve, called the liberal test, is based on the Poisson distribution, which is applicable when the probability of an event is low and the population in which it occurs is large. The second curve, an application of the chi-square test, can be used to minimize the chance of calling a reduction significant when it is not. Curve 2, referred to as the conservative test, should be used when the before accident data are limited in number. Each of the curves is to be used only on before and after studies of the same roadway sections. The use of similar curves was explained by Laughland et al. in 1975.[33] In the latter case, however, the second curve was based on a Poisson comparison of means test and differs slightly from that originally presented by Michaels. For the 95% confidence level, curves 1 and 2 and the curve similar to number 2 given by Laughland et al. are shown in Figure 5.

These curves are based on the number of accidents occurring before a highway improvement (horizontal axis) and the percent reduction required to be significant (vertical axis). For the present study, the before accidents are the number of "lighting off" accidents since the testing is being done to see if the "lighting on" case provides significant reductions. Since the concern is with an analysis of the effect of illumination, only the number of night accidents occurring during the "lighting off" period is used. As an example, 51 accidents occurred during the December through February period with the lighting off. With the lighting on during the same period a year earlier, the accident rate ratio was 44% lower. Because the number of accidents can be considered limited, curve 2, the conservative test, should be used. Referring again to Figure 5, the indication is that the results are significant at the 95% confidence level, since the data point is above the second curve as well as the comparison of means curve. Another way of viewing this particular result is to note that only 32 accidents would have been required for the 44% reduction to have been significant.

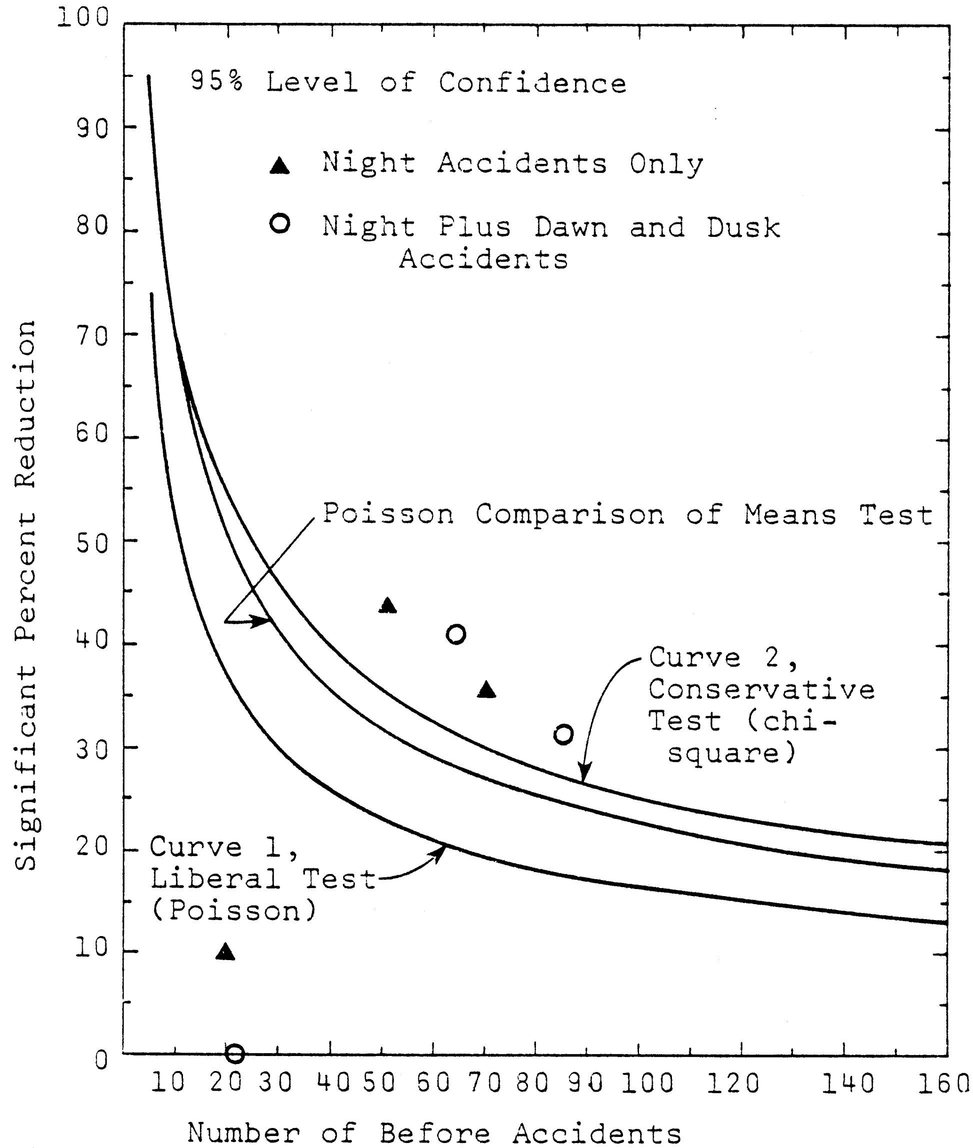

Figure 5. Curves that can be used to test for statistical significance of reductions in accidents. (After Michaels[32] and Laughland et al.[33].)

The remaining reductions in accident rate ratios from Table 6 were tested as shown by the points indicated on the curve chart. The 10% reduction in the accident rate ratio for the March through May period was not significant, due largely to the small number of accidents involved in the test. For the full six-month period from December through May, however, the reduction in the rate ratio was significant. Parallel results were obtained when the night- (including dawn and dusk)-to-day accident rate ratios from Table 7 were tested. Therefore, it is concluded that the lighting on the study section did reduce the night accident rate and that there was only a 5% probability that the reduction occurred merely by chance.

Comparison of Results to an Unlit Control Section

To afford a further check on the validity of the results of the comparative study, data for an unlit control section equal in length to the main study section were reviewed. The unlit I-95 control section lies immediately south of the main study section (see Figure 1). No night traffic counts are taken on this section of I-95, but day counts are taken routinely at several stations. In the absence of night traffic counts a reasonable assumption would be that the average composite night and day traffic volumes would have been proportional to those on the main study section. This procedure, though not ideal, can be supported by a finding from the study by Box.[28,29] He found that 25% of the urban freeway traffic volume occurs at night and this fact can be used to calculate rate ratios in the absence of traffic counts. Therefore, the composite night and day traffic volumes for the control section were estimated by proportioning the composite volumes of the main section to the ratio of the actual average daytime volume on the control section to that of the main section. From these data, the day and night accident rates and the night-to-day accident rate ratios were calculated. The results are presented in Table 8. The accident rate ratios on the control section for the two comparative six-month periods were, respectively, 1.30:1 and 1.46:1.

To test these data for significance in a manner to parallel that used for the main study section, the curves of Figure 5 were again applied. There was an 11% difference between the two ratios. Considering the 49 accidents involved in the test for significance, this data point falls well below the conservative test curve so it can be concluded that there was no significant difference between the two rate ratios at the 95% confidence level. Thus, the earlier conclusion concerning the main study section was substantiated by the control section data.

Table 8

Unlit Control Section Data

Period	Months	No. of Accidents		Accident Rate		Night-to-Day Rate Ratio
		Day	Night	Day	Night	
1972-1973	D,J,F,M,A,M	137	87	192.65	251.34	1.30
1973-74	D,J,F,M,A,M	90	49	144.27	210.65	1.46

Conclusions

Prior Studies

1. Earlier studies have shown that lighting streets, intersections, and general nonlimited access highways reduces the nighttime accident rate on these facilities.

2. An evaluation of the early research concerning accidents on lighted freeways indicated that a lack of before and after study situations on the same sections of roadway, plus other problems associated with obtaining desirable study conditions, may have limited the significance of much of the work and contributed to some of the concern about the effectiveness of freeway lighting. More recent studies that employed more refined techniques of data analysis on a number of freeways concluded that freeway lighting is beneficial in reducing the night accident rate.

The Virginia I-95 (Shirley Highway) Study

1. The comparative study of six months of accident data on a 13.8 km (8.57 mi) section of continuous freeway lighting on I-95 (Shirley Highway) contrasted the "lights on" and the "lights off" conditions. It was concluded that the continuous freeway lighting reduced the nighttime accident rate on this section of roadway. The results of the full six-month study period were found to be significant at the 95% confidence level.

2. A comparative study of the first three months of accident data during December through February (when heavy traffic volumes occur during the early hours of darkness) indicated that lighting was highly effective in reducing the accident rate during this period.

3. Although the number of night accidents that were reported during the March through May period were not sufficient to provide statistical significance to the results for this period, the data suggest that the lighting may not be as effective during the spring and summer seasons when the hours of daylight are longer and as a consequence the night traffic volumes lower.

4. The results of the study suggest that future strategies for reducing energy consumption in freeway lighting that include turning the lighting off must consider possible adverse effects on highway safety.

Recommendations

The earlier findings of a more limited accident study of the I-95 lighting were used in that the lighting, which had been turned off, was reactivated. The data reported in this report are the results of a more refined analysis applied to a longer study period. The overall conclusion, i.e., that the continuous lighting reduces the night accident rate, is the same as that reported earlier. All plans for reducing energy consumption by turning off entire sections of freeway lighting should be carefully considered with regard to possible adverse effects on the nighttime accident rate.

Since the speed limit was reduced during the "lights off" period of the study reported here, a comparison should be made between these data and more recent data with the lights on under the reduced speed limit.

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