9. J.S. Smyth. The Brightness and Legibility at Night of Road Traffic Signs. Transactions of the Illuminating Engineering Society. Vol. 12, No. 4, 1947, pp. 71-94.
10. T.W. Forbes, B.B. Saari, W.H. Greenwood, J.G. Goldblatt, and T.E. Hill. Luminance and Contrast Requirements for Legibility and Visibility of Highway Signs. In Transportation Research Record 562, TRB, National Research Council, Washington, D.C., 1976, pp. 59-72.
11. B.L. Hills and K.D. Freeman. An Evaluation of the Luminance Contrast Requirements in Fully Reflectorized Signs. Proc., 5th Australia Road Research Board Conference. Nunawading, Victoria, Australia, Vol. 5, No. 3, 1970, pp. 67-94.
12. M. Sivak, P.L. Olson, and L.A. Pastalan. Effect of Driver's Age on Nighttime Legibility of Highway Signs. Human Factors. Vol. 23, 1981, pp. 59-64.
13. M. Sivak and P.L. Olson. Nighttime Legibility of Traffic Signs: Conditions Eliminating the Effects of Driver Age and Disability Glare. Accident Analysis and Prevention. Vol. 14, 1982, pp. 87-93.
14. B.L. Cole. Visual Aspects of Road Engineering. Proc., Australian Road Research Board, Nunawading, Victoria, Australia, Vol. 6, No. 1, 1972, pp. 102-148.
15. A. Burg. Visual Acuity as Measured by Dynamic and Static Tests: A Comparative Evaluation. Journal of Applied Psychology. Vol. 50, 1966, pp. 460-466.
16. T.M. Allen. Night Legibility Distances of Highway Signs. Bull. 191. Highway Research Board, National Research Council, Washington, D.C., 1958, pp. 33-40.
17. W.C. Richardson. Comparison of Legibility Potential of Reflective Sign Components. Ohio Department of Transportation, Columbus, July 1976.
18. H.L. Woltman and W.P. Youngblood. An Assessment of Indirect Factors Affecting Reflective Sign Brightness. Paper presented at the 1976 Annual Meeting of the Transportation Research Board, Washington, D.C., Jan.
19. P.L. Olson and M. Sivak. Improved Low-Beam Photometrics. Interim Report UM-HSRI-81-4. Highway Safety Research Institute. University of Michigan, Ann Arbor, Feb. 1981.
20. J.A. Hicks, III. An Evaluation of the Effect of Sign Brightness on the Sign Reading Behavior of Alcohol Impaired Drivers. Human Factors. Vol. 18, 1976, pp. 45-52.
21. J.W. Anderson and G.C. Carlson. Vehicle Spray Pattern Study. Investigation 338, Minnesota Highway Department, St. Paul, Aug. 1966.
22. N.T. Cox. The Effect of Dirt on Vehicle Headlamp Performance. RRL Report LR 240. Road Research Laboratory, Crowthorne, Berkshire, England, 1968.
23. P.L. Olson and R.G. Mortimer. Analysis of Sources of Error in Headlamp Aim. SAE Report 740312. Highway Safety Research Institute, University of Michigan, Ann Arbor, 1974.

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Freeway Lighting and Traffic Safety—A Long-Term Investigation

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ABSTRACT

The objective of this study was to assess the effectiveness of freeway lighting. To achieve this, a case study on traffic accident characteristics was conducted that utilized a suburban freeway area west of Frankfurt, Federal Republic of Germany, between 1972 and 1981. The study revealed that (a) the effects of lighting on suburban freeway accident rates was positive--there was a reduction in accidents, and (b) these positive results of continuous freeway lighting were lost in the case of partial lighting, especially after switching off lights at night between 10:00 p.m. and 5:30 a.m. for the purpose of saving energy.

Sufficient reliable documentation is available to support the assumption that nighttime traffic accident rates are considerably higher than daytime rates. For example, the National Safety Council has determined that in both urban and rural areas, the mileage death rates at night are at least 4 times higher than death rates during the day (1). Also, in the Fatal Accident Reporting System (2), it was reported that

> There is a distinct pattern of fatalities by time of day and day of week. A greater number of fatalities occurred from 4:00 to 8:00 p.m. on weekdays and from midnight to 4:00 a.m. on weekends. The weekends, however, had the highest concentration of fatalities [during nighttime].

There are many reasons for the unbalanced night accident rate. The following are but a few of the factors that cause driving at night to be hazardous (3).

1. The average person is poorly equipped to see adequately at night. This problem becomes more serious as a person grows older. For example, the glare resistance of the over-65-year-old driver is one-third that of the 25-year-old driver (4). Persons who are 60 years old require 8 times as much light as those 20 years old. Therefore, many of the driving assignments that involve such factors as speed and roadway conditions become more difficult and hazardous to most drivers when confronted with darkness (5).
2. The physical condition of the average driver must be recognized. Fatigue, drowsiness, influence of alcohol, and psychological aspects all have a definite influence on an individual's driving ability, especially at night (3).
3. There is a lack of understanding by many motorists and pedestrians regarding the hazards of night driving.

Many experts generally agree that the use of lighting is justified as a safety improvement because it reduces the frequency as well as the severity of accidents (6). In addition, it provides peace of mind to the traveling public, affords protection to pedestrians, reduces crime, and enhances street appearance (3).

A literature review revealed positive effects of lighting on reducing the frequency, as well as the severity of accidents on urban streets, regular highways, and at intersections. With regard to the effects of freeway lighting on traffic safety, however, mixed opinions were observed. Although several studies concluded that continuous freeway lighting reduces nighttime accident rates and that lighted freeways have significantly lower accident potential than unlighted ones, other studies more or less indicated that continuous freeway lighting did not reduce nighttime accidents.

CASE STUDY

To obtain a better understanding of the effect of lighting, an analysis was conducted from 1972 to 1981 of traffic accident characteristics on a suburban freeway (see Figure 1) area west of Frankfurt,

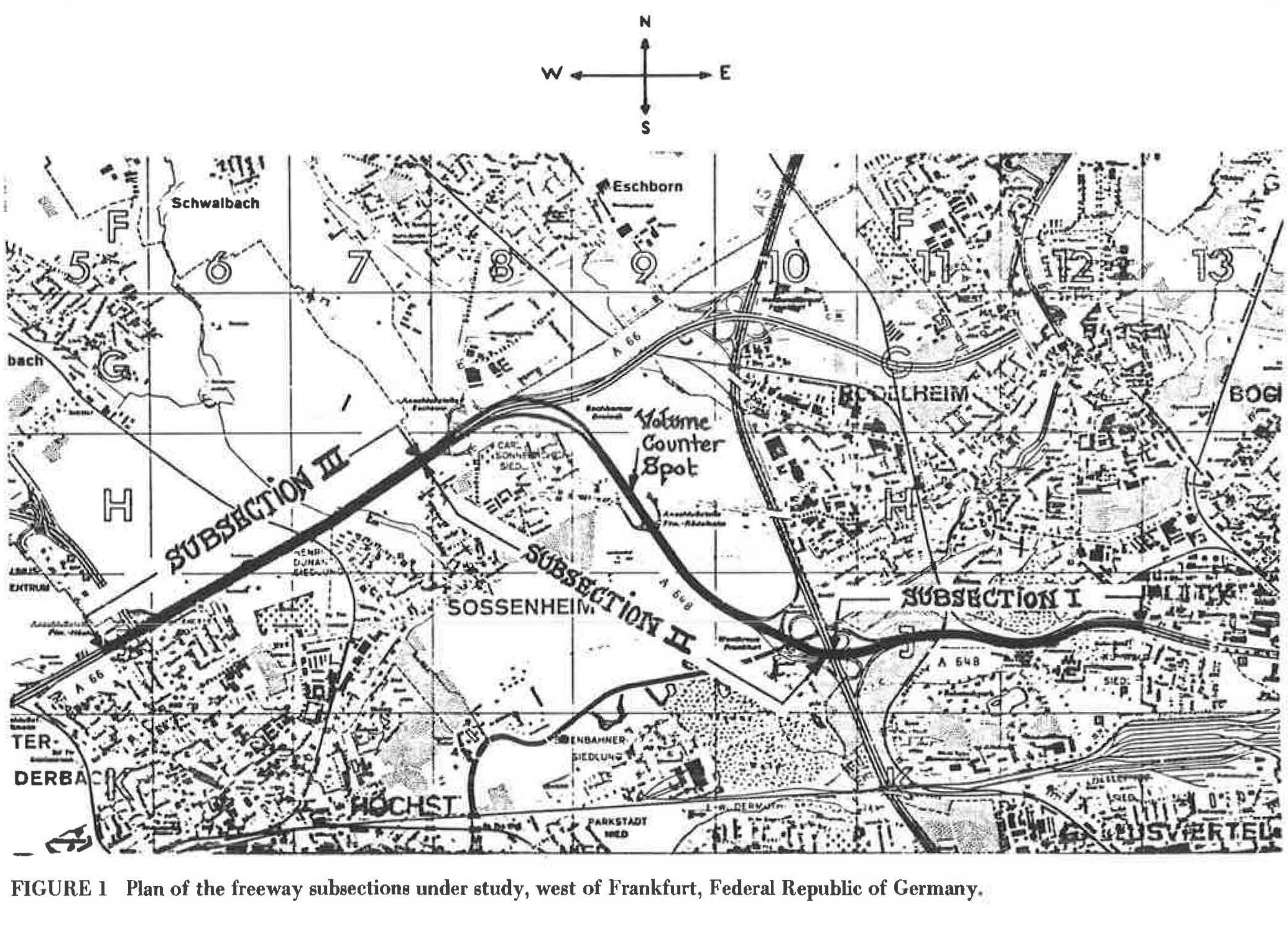

FIGURE 1 Plan of the freeway subsections under study, west of Frankfurt, Federal Republic of Germany.

Federal Republic of Germany (7). Although the freeway section (German Autobahn A648/A66) is heavily developed along the right-of-way, it has a full control of access. Between the interchanges, the divided freeway consists of two lanes in each direction (lane width 3.75 m) with an additional emergency lane (lane width 2.5 m) and unpaved shoulders (width 1.5 m) on each side. The median is approximately 3 m wide and contains a double blocked-out metal beam barrier and a fence to minimize headlight glare. On part of the freeway section under study, lighting devices were installed in 1973. Typical suburban traffic was dominant on this section. (Note: No major construction zones or lane closures were present at the time the study was conducted.)

It is stated in the German Standard (DIN 5044, Part I) that:

> Freeways (Autobahnen) with a traffic volume of 900 vehicles per hour or more and a speed limit of $V \leq 110$ km/h (as is the case of the present study), should be provided with fixed highway lighting with an illuminance level (Nennleuchtdichte) of 1 candela per square meter and a uniformity ratio (Laengsgleichmaessigkeit) of 0.7.

The uniformity ratio is defined as the minimum illuminance level divided by the maximum illuminance level. In a telephone conversation with a representative at the Ministry of Economy and Technique of the state of Hessen, Federal Republic of Germany, in early 1985, it was confirmed that the previously stated lighting values were maintained during the entire study period.

THE INVESTIGATED FREEWAY SECTION

The freeway section studied was divided into three subsections: two were lighted and the third was unlighted for a parallel study. The three freeway subsections under study are shown in Figure 1. Subsection 1 (a) is 1.9 km long; (b) is equipped with cable-suspended luminaires (high-pressure sodium, 250 W) at heights of 12 m, 20 to 21 m apart, on poles installed in the middle of the median and protected by longitudinal barriers; and (c) consists of relatively flat curves with radii $\geq$ 1000 m that correspond to a design speed of 120 km/h (75 mph) (8). Subsection 2 (a) is 3.7 km long; (b) is equipped with cable-suspended luminaires, as described under subsection 1, until approximately the volume counter spot (see Figure 1) after which high mast lighting with luminaires (400 W) are mounted on poles at heights between 25 to 31 m; and (c) consists of flat curves until the volume counter spot and then of curves of minimum radii of 600 m that correspond to a design speed of 100 km/h (62.5 mph) (8).

Because radii $\geq$ 600 m do not substantially affect changes in operating speeds, the effect of the horizontal alignment on the accident situation may be excluded (9). Following subsections 1 and 2 is an unlighted straight subsection 3 that is 2.3 km long.

ASSUMPTIONS AND DEFINITIONS

The period of investigation from 1972 to 1981 was divided into the categories shown in the following table:

Investigation Period	Duration
Before	December 5, 1972 to December 4, 1973
After 1	December 5, 1973 to November 14, 1978
After 2	November 15, 1978 to November 14, 1981

During the before period (B), all subsections were unlighted. During the first after period (A1), subsections 1 and 2 were lighted from dusk to dawn, and subsection 3 was unlighted. During the second after period (A2), subsection 1 was lighted from dusk to dawn and subsection 2 was lighted from dusk until 10:00 p.m. Between 10:00 p.m. and 5:30 a.m., subsection 2 was unlighted. From 5:30 a.m. until dawn, subsection 2 was lighted only if necessary. In summary, the lighting conditions on the investigated subsections are given in Table 1.

TABLE 1 Lighting Conditions on the Three Subsections Investigated

Subsection	B	A1	A2
1	●	O	O
2	●	O	Δ
3	●	●	●

Note: ● = unlighted, ○ = lighted, and Δ = partially lighted.

It should be noted that in the following text the term "day" (dawn to dusk) means the period between the morning after sunrise until the evening before sunset. The term "night" (dusk to dawn) means the period between the evening after sunset until the morning before sunrise.

The basis for the investigation was accident reports filed by the police over a 9-year period. Overall, 1,899 accident reports were surveyed. Approximately 52 percent of the accidents occurred in the east-west direction, and 48.3 percent occurred in the west-east direction. No vehicle-pedestrian accidents were observed on the study section. Accident types that will not be analyzed in this study because of the limited data base can be broken down as follows:

Type of Accident	Total Occurrences (%) Day	Night
Run off the road	18.5	37.1
Rear-end collisions	31.3	19.4
Passing collisions	5.1	6.0
Changing lanes	17.5	13.6
Merge, diverge collisions (only related to the through-traffic lanes, not the ramps)	15.3	10.4
Others	12.4	13.4

Another factor considered is the vehicle kilometers of travel (VKT) produced on the freeway subsections investigated. The average daily traffic (ADT) values were calculated from the yearly data collection of traffic volumes conducted by the federal government (see the following table):

	Subsection 1	Subsection 2	Subsection 3
Before (B)	53,400	51,500	64,700
After 1 (A1)	59,600	54,200	69,000
After 2 (A2)	53,500	48,500	77,100

For a clear comparison of day versus night accident developments (that do not necessarily conform to the definition given in the police records), the exact times of sunrise and sunset were determined for each day of the year. Thus, for each month of the year, the percentages of the VKT could be calculated for day and night. For example, the data in

TABLE 2 Determination of Day and Night Vehicle Kilometers of Travel for a Typical Year in the Investigated Period at the Volume Counter in Subsection 2

HOUR	JAN %	FEB %	MARCH %	APR %	MAY %	JUNE %	JULY %	AUG %	SEP %	OCT %	NOV %	DEC %
11 p.m.	1.61	1.51	1.41	1.30	1.41	1.45	1.49	1.54	1.63	1.72	1.82	1.72
10 p.m.	1.79	1.70	1.60	1.51	1.99	1.97	1.95	1.93	1.94	1.96	1.97	1.88
9 p.m.	2.21	2.20	2.20	2.19	2.25	2.19	2.13	2.07	2.12	2.17	2.23	2.22
8 p.m.	3.39	3.24	3.09	2.94	3.26	3.28	3.30	3.32	3.44	3.57	3.69	3.54
7 p.m.	5.17	4.91	4.65	4.39	4.62	4.68	4.74	4.80	5.09	5.38	5.68	5.43
6 p.m.	6.64	6.54	6.43	6.33	6.47	6.46	6.45	6.43	6.57	6.71	6.85	6.75
5 p.m.	7.81	7.79	7.77	7.74	7.80	7.91	8.03	8.15	8.05	7.95	7.85	7.83
4 p.m.	8.40	8.47	8.54	8.61	8.05	8.23	8.37	8.60	8.49	8.38	8.27	8.34
3 p.m.	6.64	6.66	6.68	6.69	6.59	6.57	6.55	6.53	6.55	6.57	6.60	6.62
2 p.m.	5.87	5.87	5.86	5.85	5.52	5.58	5.64	5.70	5.76	5.82	5.88	5.88
1 p.m.	5.48	5.46	5.44	5.43	5.31	5.34	5.37	5.40	5.43	5.46	5.50	5.49
Noon	4.98	5.04	5.10	5.16	5.12	5.10	5.08	5.06	4.99	4.92	4.85	4.91
11 a.m.	4.76	4.87	4.98	5.09	5.02	5.02	5.02	5.02	4.86	4.70	4.54	4.65
10 a.m.	5.25	5.35	5.45	5.55	5.17	5.18	5.19	5.20	5.15	5.10	5.04	5.14
9 a.m.	5.71	5.82	5.93	6.03	5.79	5.69	5.59	5.49	5.49	5.50	5.50	5.60
8 a.m.	7.13	7.02	6.91	6.80	6.84	6.90	6.96	7.01	7.12	7.23	7.35	7.24
7 a.m.	8.16	8.16	8.15	8.15	8.42	8.36	8.30	8.24	8.22	8.20	8.17	8.17
6 a.m.	5.94	6.22	6.50	6.78	6.65	6.34	6.02	5.70	5.59	5.48	5.38	5.66
5 a.m.	1.27	1.36	1.45	1.53	1.63	1.56	1.48	1.40	1.29	1.19	1.09	1.18
4 a.m.	0.32	0.32	0.33	0.33	0.44	0.41	0.38	0.35	0.34	0.33	0.31	0.31
3 a.m.	0.19	0.19	0.19	0.19	0.22	0.21	0.20	0.19	0.19	0.19	0.19	0.19
2 a.m.	0.27	0.28	0.28	0.28	0.27	0.28	0.30	0.31	0.30	0.28	0.27	0.27
1 a.m.	0.44	0.45	0.46	0.46	0.43	0.48	0.53	0.58	0.53	0.48	0.42	0.43
Midnight	0.72	0.70	0.69	0.67	0.72	0.81	0.90	0.98	0.91	0.84	0.76	0.74
Night-	38.12	23.08	11.70	6.93	5.04	5.20	5.37	7.95	12.69	23.59	30.66	38.49%
Day-	61.88	76.92	88.30	93.07	94.96	94.80	94.63	92.05	87.31	76.41	69.34	61.51%

Legend: ——— change between dawn and dusk, respectively between dusk and dawn.

Table 2 indicate that for a typical year, 38.5 percent of the VKT occurred at night during the month of December, whereas only 5.2 percent of the VKT occurred at night during the month of June. On the average, for the 9-yr period investigated, 81.1 percent of the VKT occurred during the day compared with 19.9 percent at night (7).

DEVELOPMENT OF THE ACCIDENT SITUATION

The analysis of the accident situation on the freeway section investigated is based on the total number of accidents as follows:

Period	Total Accidents: Subsection 1 Day	Subsection 1 Night	Subsection 2 Day	Subsection 2 Night	Subsection 3 Day	Subsection 3 Night
B	61	30	102	46	62	19
A1	148	77	316	121	266	114
A2	55	39	141	85	144	73

The corresponding accident rates (accidents per 10^6 VKT) are given in Table 3, and the accident cost rates for all accidents (German Marks per 100 VKT) are given in Table 4.

Before discussing the analysis, it is important to note that the rate for personal injury accidents has decreased steadily in the Federal Republic of Germany since 1972. Factors that may have contributed to this decrease include the energy crisis of 1973-1974, the introduction of a general speed limit of 100 km/h on 2-lane rural roads in 1973, the introduction of a strict anti-drunk driving law, which set a BAC at 0.08 percent as the intoxication level in 1973, the mandatory use of seat belts in front seats, and the mandatory safety-helmet law for motorcyclists that was put into effect in 1976 (10).

A decrease in the accident rate on the investigated freeway section should therefore be expected, aside from the installation of lighting devices. For example, the following table, which shows the development of the rate for personal injury accidents on the investigated three subsections and on the whole

TABLE 3 Accident Rates (per 10^6 VKT) During the Different Time Periods for Day and Night Conditions on the Three Subsections Investigated

	Subsection 1			Subsection 2			Subsection 3		
	Day	Night	N/D Ratio	Day	Night	N/D Ratio	Day	Night	N/D Ratio
B	2.03	4.28	(2.1)	1.83	3.33	(1.8)	1.41	1.85	(1.3)
	x	x		x	x		0	0	
A1	0.88	1.97	(2.2)	1.08	1.66	(1.5)	1.13	2.08	(1.8)
	x	0		0	x		x	0	
A2	0.62	1.76	(2.8)	0.90	2.18	(2.4)	0.93	1.89	(2.0)

Note: x = significant at the 95 percent level of confidence, 0 = nonsignificant at the 95 percent level of confidence, and N/D = night/day ratio of accident rates.

TABLE 4 Accident Cost Rates (German marks per 100 VKT) During the Different Time Periods for Day and Night Conditions on the Investigated Three Subsections

	Subsection 1			Subsection 2			Subsection 3		
	Day	Night	N/D Ratio	Day	Night	N/D Ratio	Day	Night	N/D Ratio
B	4.90	15.99	(3.3)	4.07	8.40	(2.1)	2.66	6.25	(2.3)
A1	1.98	5.85	(2.9)	2.55	4.42	(1.7)	3.17	5.30	(1.7)
A2	1.32	3.44	(2.6)	1.58	4.33	(2.7)	1.69	3.18	(1.9)

Note: N/D ratio is the night/day ratio of accident cost rates, and $1.00 (U.S.) corresponds to about 2.7 German Marks (GM). For the calculation of the accident cost rate, the following assessments of personal injuries were applied: fatally injured–500,000 GM, heavily injured–55,000 GM, and lightly injured–10,000 GM. The costs of property damage accidents were compiled from police records.

interstate (freeway) network system in the Federal Republic of Germany, clearly supports the assumption.

	B	A1	A2
Interstate network	0.36	0.23	0.20
Subsection 1	0.86	0.29	0.16
Subsection 2	0.56	0.32	0.22
Subsection 3	0.31	0.29	0.19

Also, it is interesting to note that on the one hand, the accident rates on the unlighted subsection 3 for the years 1973, 1976, and 1980 nearly correspond to that on the whole interstate (freeway) network system in the Federal Republic of Germany, while on the other hand, the continuously lighted subsection 1 showed the strongest decrease from 0.86 to 0.16, followed by the partially lighted subsection 2 from 0.56 to 0.22.

SUBSECTION 1

On the average, 33 percent of property damage accidents and 43 percent of personal injury accidents occurred on this subsection at night. Accidents per 10^6 VKT and accident cost rates (German Marks per 100 VKT) showed evident reductions on this subsection during day and night conditions (see Tables 3 and 4). Note that subsection 1 was continuously lighted during the periods A1 and A2 (see Table 1).

For day and night conditions, the development of the accident situation between the B, A1, and A2 periods is nearly parallel. This means that the reduction in accident rates and accident cost rates of accidents occurring during night conditions after the installation of lighting devices can be noticed also for day conditions. A comparison of the lighted subsection 1 with the unlighted subsection 3 reveals that accident rates and accident cost rates showed more favorable reductions, especially on subsection 1 during night conditions.

Furthermore, it is interesting to note that although the night-to-day ratio of accident rates for subsection 1 was increasing, the night-to-day ratio of accident cost rates, which accurately represents the severity of accidents, was decreasing between the B, A1, and A2 periods from 3.3 to 2.9 to 2.6 (German Marks per 100 VKT), respectively (see Table 4).

SUBSECTION 2

On the average, 29 percent of property damage accidents and 38 percent of personal injury accidents occurred on subsection 2 at night. Between the B and A1 periods, accident rates and accident cost rates were nearly cut in half. With the introduction of partial lighting on this subsection (see Table 1), it is interesting to see that between periods A1 and A2, accident rates and accident cost rates under night conditions remained at nearly the same level or even increased (see Tables 3 and 4).

Between periods B and A1, the reduction in accident rates and accident cost rates on this subsection is nearly parallel for day and night conditions. In contrast, between periods A1 and A2, the reduction continued under day conditions although it remained at nearly the same level or even increased under night conditions.

Comparing the night-to-day ratio of accident rates and accident cost rates in Tables 3 and 4, the preceding statement is supported by the decrease of the ratios from 1.8 to 1.5, respectively; and from 2.1 to 1.7 between the B (unlighted) and the A1 (lighted) periods. However, when partial lighting was introduced on this subsection in the A2 period, the night-to-day ratios showed a strong increase from 1.5 to 2.4, respectively, and from 1.7 to 2.7 (see Tables 3 and 4).

SUBSECTION 3

On the average, 30 percent of property damage accidents and 31 percent of personal injury accidents occurred on subsection 3 at night. This means that contrary to subsections 1 and 2, there was no evident difference between the accident categories, "property damage" and "personal injury" accidents. Although no lighting devices were present on this subsection (see Table 1), reductions in accident rates for the subsection can be noticed (see Tables 3 and 4). These reductions were, in general, not as strong as those on subsections 1 and 2. The night-to-day ratios reveal increases in accident rates and fluctuations in accident cost rates on the unlighted subsection 3.

THE EFFECTS OF PARTIAL LIGHTING

Although no clear conclusions have yet been drawn about the effectiveness of lighting, it should be mentioned here that further reductions in accident rates and accident cost rates under day conditions on subsection 2 could be observed between periods A1 and A2. In contrast, after several observations during night conditions, the reduction in accident rates and accident cost rates showed almost no decrease and, in some observations, even increased after the introduction of partial lighting (see Tables 3 and 4). Contrary to this development, accident rates and accident cost rates showed further decreases between periods A1 and A2 on subsection 1 under night conditions. The same is also true for the reduction in accident and cost rates on the unlighted subsection 3.

To draw more reliable conclusions about the effect of lighting on night accidents, the daytime period of 24 hr was divided into the time periods: Day, Dark 1, and Dark 2 (see Figure 2). (In Figure 2, period Day lasts from sunrise to sunset, period Dark 1 lasts from sunset until 10:00 p.m. and from 5:30 a.m. until sunrise, and period Dark 2 lasts from 10:00 p.m. until 5:30 a.m.)

Overall, the accident rates in Figure 2 appear to agree with the results of many findings, for example, that driving during the hours of day, and from sunset to about 10:00 p.m. and from about 5:30 a.m. to sunrise, is much safer than driving during the night hours between 10:00 p.m. and 5:30 a.m., regardless of the lighting conditions (1,2,11).

Under day conditions, Figure 2 shows that the reduction in accident rates is stronger on subsection 1 than on subsection 3. Different development could be noticed under Dark 1 conditions. For example, after the introduction of lighting in December 1973, a sharp decrease in the accident rates could be noticed on subsections 1 and 2 between the B and A1 periods. However, this reduction remained at nearly the same level between the A1 and A2 periods on both sections. In contrast, the accident rate on subsection 3 showed an increase between the B and A1 periods, although it remained at nearly the same level between the A1 and A2 periods.

Under Dark 2 conditions, the accident rate decreased strongly on subsections 1 and 2 between the B and A1 periods. While this reduction continued on subsection 1 (lighted) between the A1 and A2 periods, it increased strongly on subsection 2 (not

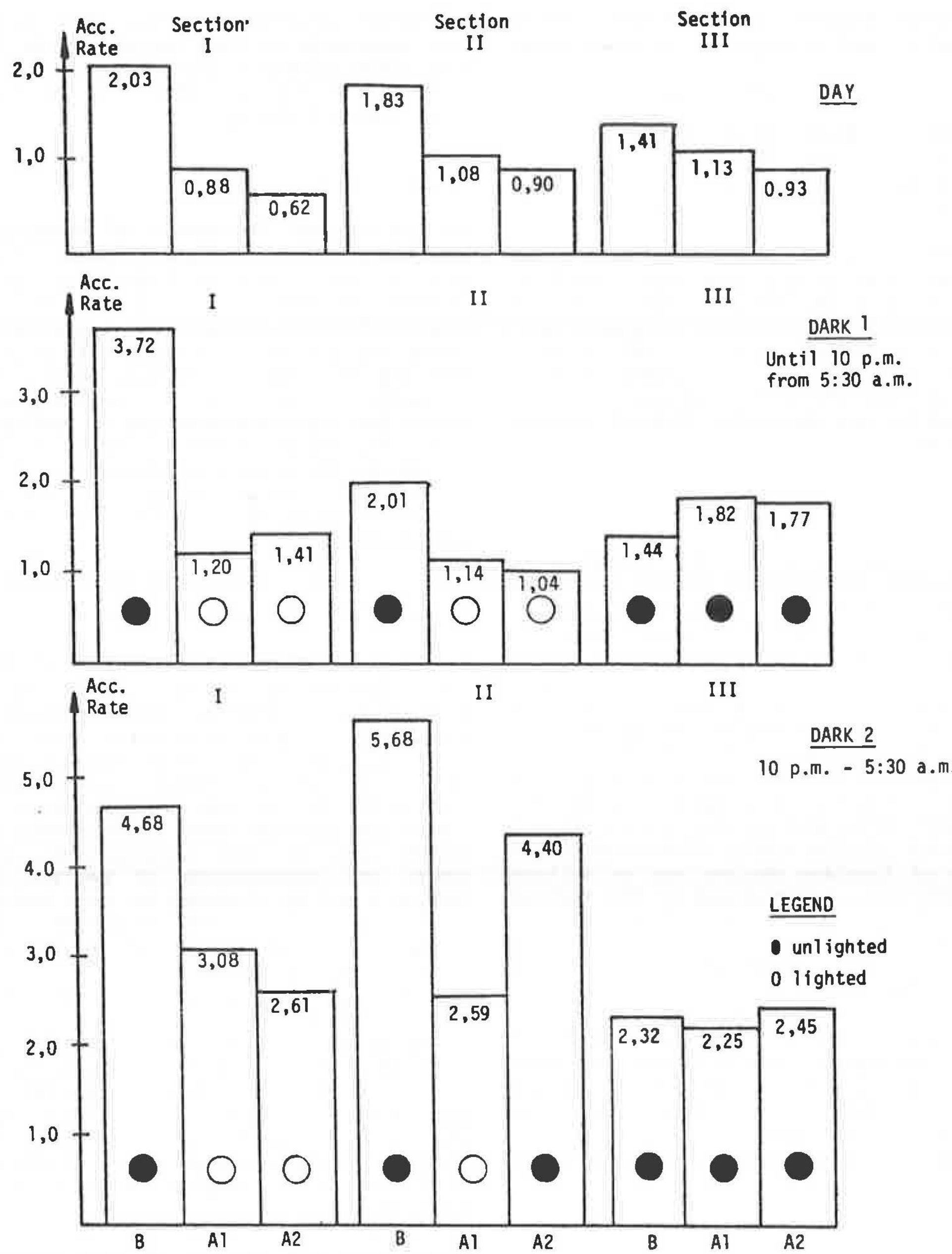

FIGURE 2 Accident rates for Day, Dark 1, and Dark 2 daytime periods with identification of lighting conditions.

lighted) between the same periods. During the 9-yr investigation period, the accident rate on subsection 3 revealed no significant changes among the 3 periods during the late night hours.

CONCLUSION

The case study revealed that positive effects of lighting on reducing accident rates and accident cost rates on freeways in suburban areas cannot be excluded, even if no real convincing results could be statistically proven. However, it should be noted that the positive results obtained through continuous lighting were lost in the case of partial lighting for energy conservation purposes. The increase in accident rates after switching off lights at night between 10:00 p.m. and 5:30 a.m. especially supports this statement. The savings in energy costs after switching off lights as compared with savings in accident costs could not be determined in this study.

It is obvious that this research is a small step toward determining the effectiveness of freeway lighting in terms of safety. Further research is needed to verify and add to the findings of this study.

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REFERENCES

1. Accident Facts. National Safety Council, Washington, D.C., 1982
2. Fatal Accident Reporting System. National Highway Traffic Safety Administration, U.S. Department of Transportation, 1978.
3. M.C. Sielski. Relationship of Roadway Lighting and Traffic Accidents. In HRB Special Report 93: Improved Street Utilization Through Traffic Engineering, HRB, National Research Council, Washington, D.C., 1967, pp. 172-177.
4. B.W. March. Aging and Driving. Traffic Engineering, Nov., 1960.
5. M.C. Sielski. Night Visibility and Traffic Improvement. American Automobile Association, Falls Church, Va., 1965.
6. Effectiveness of Freeway Lighting. Report FHWA-RD-79-77. FHWA, U.S. Department of Transportation, Feb., 1980.
7. R. Lamm, J.H. Kloeckner, and A. Nickpour. Effect of Interstate Illumination on Traffic Safety, Ministry of Economy and Technique, Final Report, State Hessen, Federal Republic of Germany, Nov., 1982.
8. Guidelines for the Design of Rural Roads. Report RAL-L-1. German Road and Transportation Research Association Committee 2.3, Geometric Design Standards, Federal Republic of Germany, 1973.
9. R. Lamm. Driving Dynamics and Road Characteristics--A Contribution for Highway Design Under Special Consideration of Operating Speeds, Vol. II. The Institute of Highway and Railroad Design and Construction, University of Karlsruhe, Karlsruhe, Federal Republic of Germany, 1973.
10. R. Lamm, F.B. Lin, E.M. Choueiri, and J.H. Kloeckner. Comparative Analysis of Traffic Accident Characteristics in the United States, Federal Republic of Germany, and Other European Countries. Research report for Alfreid Krupp von Bohlen und Halbach-Stiftung, Essen, Federal Republic of Germany, Sept. 1984.

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ABSTRACT

This paper contains data on the detection distances of reflectorized white license plates. Detection distances were obtained for a car heading angle and a driver's line of sight in 5 different treatments with 12 drivers. The order of presentation of the five treatments for a given heading angle was basically random and approximately balanced. Each driver sat in a stationary car on a 2,000-ft long runway and detected an approaching target configuration under low beam conditions against a background containing a number of luminaires and other light sources. There were three parallel approach paths on the runway and for each treatment, three approaches were made on each path toward a driver. The results of this study indicated that the average detection distance increase from treatment 1 to treatment 5 was 39 percent for the -3-degree heading angle and 85 percent for the 10-degree heading angle. Based on the detection distances obtained in this study and calculations that involve stopping sight distances and/or decision sight distances, the potential for significant safety benefits when using reflectorized license plates in addition to the red rear cube corner vehicle reflectors can be demonstrated. These potential safety benefits are especially significant for an 84-CIL license plate combined with two red rear reflectors.

Reflectors and reflectorized license plates have been in use for many years as a means of aiding the driver in the initial detection, recognition, and identification of stationary vehicles on or off the roadway at night with no lights on. Several studies have been conducted that compare accident rates of vehicles with reflectorized versus nonreflectorized license plates. Henderson, Ziedman, Burger, and Cavey reviewed and summarized a number of these studies (1). In the past, Hulbert and Burg, Cook, and Sivak and Olson reviewed license plate and reflectorization studies (2-4).