As would be expected, subject vehicles following signaling left turners indicated an overwhelming preference for the through lane vis-a-vis the common left-and-through approach lane. It is of interest, however, that in certain instances subject vehicles behaved similarly when isolated from other vehicles as compared to cases in which they followed nonsignaling leaders, even though the latter could be eventually executing a left turn. In other words, a number of subject vehicles would have selected a different approach lane had they been apprised of the turning intention of the vehicle ahead. The ultimate implication of this discrepancy on traffic safety and efficiency must await further examination. With respect to traffic safety, a study of the correlation between certain types of conflicts on the one hand and the pattern of turn signal use on the other within the general framework of conflict analysis (5) may prove fruitful. In addition, based on the findings of the current study, it appears that the investigation of other situations involving the use of turn signals (for example, lane changing) and the study of more complex cases in the vicinity of signalized intersections are warranted.

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Cost-Effectiveness Evaluation of Rural Intersection Levels of Illumination

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ABSTRACT

Lighting is often installed at rural intersections to improve the safety of night traffic operations at these locations. However, there are no generally accepted design criteria that define the levels of illumination required at rural intersections. The objective of this research was to evaluate the cost-effectiveness of rural intersection levels of illumination. Six lighting systems were installed at a rural, unchannelized intersection of two two-lane highways. Speed-profile and traffic-conflict studies were conducted on an uncontrolled approach to the intersection. The studies were conducted at night at each level of illumination as well as with no lighting. The data were analyzed to determine the safety- and cost-effectiveness of each level of illumination. The results of the research indicated that, for a given luminaire wattage, two-luminaire systems provided safer traffic operations than did one-luminaire systems; and the safest operations were observed under a two 200-watt high-pressure-sodium (HPS) luminaire system. The results of the cost-effectiveness analysis revealed that lighting was not warranted at rural intersections with main highway average daily traffic less than 3,250 vehicles per day. At higher volume intersections a two 200-watt HPS luminaire system was the most cost-effective.

Lighting is installed at rural intersections to improve the safety of night traffic operations at these locations. But although several studies (1) have found improvements in highway safety as a result of intersection lighting, generally accepted warrants that define the circumstances under which the costs of installing and maintaining rural intersection lighting are justified do not exist. In addition, current guidelines for fixed roadway illumination (2-4) do not deal directly with rural intersection lighting. Thus, there are no generally accepted design criteria that define the levels of illumination required at rural intersections.

The objective of the research reported here was to evaluate the cost-effectiveness of rural intersection levels of illumination. In this research the safety-effectiveness of six levels of illumination on an uncontrolled, unchannelized approach to a rural intersection, as well as a condition of no lighting, was compared, and the most cost-effective level of illumination was identified. The procedure, findings, and conclusions of this research are presented in this paper.

PROCEDURE

Traffic-operations studies were conducted on an uncontrolled, unchannelized approach to a four-legged intersection of two rural highways. The studies consisted of the measurement of speed profiles of vehicles on the approach and the simultaneous observation of traffic conflicts on the approach. The studies were conducted at night at six different levels of illumination as well as with no lighting at the intersection.

Initially the study site was not lighted, and the traffic-operations studies were conducted at night with no illumination. When these initial studies were completed, lighting was installed at the intersection. The six lighting systems that were installed and studied are listed in Table 1. The average horizontal levels of illumination and the uniformity ratios maintained within the intersection by the six lighting systems are also given in Table 1.

TABLE 1 Lighting Systems Studied

Lighting System[a]	Avg Maintained Horizontal Illumination[b] (footcandles)	Avg/Min Uniformity Ratio[b]
One 100-watt HPS[c]	0.27	5.4
Two 100-watt HPS	0.53	2.5
One 200-watt HPS	0.39	7.8
Two 200-watt HPS	0.78	3.1
One 400-watt HPS	0.77	15.5
Two 400-watt HPS	1.70	3.3

[a]The luminaires were mounted at 400 ft and located in a catercorner configuration. The luminaire in the one-luminaire system was located on the far side of the intersection relative to the study approach.
[b]Within the intersection.
[c]High-pressure-sodium, Type II, medium-distribution, cutoff luminaires.

The speed-profile and traffic-conflicts data collected were analyzed to assess the safety effects of the six levels of illumination and a condition of no lighting. The following measures of safety-effectiveness were computed from the data for each level:

- Standard deviation of the average approach speed,
- Standard deviation of the deceleration between 900 and 300 ft before the intersection,
- Standard deviation of the deceleration between 300 and 100 ft before the intersection, and
- Overall traffic-conflicts rate.

It was assumed that the safety of traffic operations improved with lower values of each of these measures.

In addition to the calculation of these measures of safety-effectiveness, a cost-effectiveness analysis was conducted to determine the most cost-effective level of illumination. The measure of cost-effectiveness used was total annual cost: the sum of the annual cost of installing and maintaining the lighting system plus the annual cost of accidents expected to occur on the uncontrolled approaches with its use. The lighting system with the lowest total annual cost was determined to be the most cost-effective level of illumination.

The research used the Omaha Public Power District's (5) annual costs for the installation and maintenance of lighting systems. (This was the power district within which the study site was located.) The specific costs used were those for installations typical of rural intersection lighting projects designed by the Nebraska Department of Roads.

The annual accident costs were computed by using the average accident rate on the uncontrolled approaches to unchannelized, unlighted rural intersections of two-lane highways in Nebraska. It was determined from nearly 4 years of accident data (6) that the average accident rate was 1.06 accidents per million entering vehicles. It was also determined that the accident severity distribution was 5 percent fatal, 48 percent nonfatal injury, and 47 percent property-damage-only accidents. An expected accident cost of $12,175 per accident was computed by applying this distribution to 1980 accident costs of the National Safety Council.

The effect of level of illumination on the accident rate was assumed to be in proportion to the ratio of its expected accident involvement rate to the expected accident involvement rate of the condition of no lighting. The expected accident involvement rates of the levels of illumination and the condition of no lighting were computed by applying their observed average approach speed distributions to the relationship between night accident involvement rate and speed, which was determined by Solomon (7) from a study of rural highway sections. In addition to determining the most cost-effective level of illumination for the traffic volume conditions at the study site, the cost-effectiveness analysis was also conducted over the range of average daily traffic (ADT) levels from 500 to 7,500 vehicles per day (vpd), the approximate maximum ADT for the design of rural two-lane highways in Nebraska.

FINDINGS

The measures of safety-effectiveness computed for each level of illumination and a condition of no lighting at the study site are presented in Table 2. These values indicate that with respect to each of the measures the safest traffic operations occurred under the two 200-watt high-pressure-sodium (HPS) luminaire system. In general, according to these measures, traffic operations under the one 100-watt and two 100-watt HPS luminaire systems were not safer than those under no lighting system. Although

TABLE 2 Measures of Safety-Effectiveness of Six Levels of Illumination and Condition of No Lighting at Study Site

Lighting System	Standard Deviation: Avg. Approach Speed (mph)	Standard Deviation: Deceleration 900-300 ft[a] (fps/s)	Standard Deviation: Deceleration 300-100 ft[a] (fps/s)	Overall Traffic Conflicts Rate (no./100 vehicles)
None	8.4	0.81	1.86	3.4
One 100-watt	8.7	0.83	1.94	3.6
Two 100-watt	8.1	0.83	1.78	3.4
One 200-watt	8.1	0.82	2.01	3.0
Two 200-watt	7.6	0.67	1.42	1.9
One 400-watt	7.8	0.68	1.48	2.9
Two 400-watt	7.9	0.68	1.42	2.4

[a]Before the intersection.

these measures indicate that traffic operations under the one 400-watt and two 400-watt HPS luminaire systems were safer than those under no light system and under 100-watt lighting systems, they indicate that the two 200-watt HPS luminaire system had the lowest overall traffic conflicts rate of all systems studied. Also, the measures of safety-effectiveness indicate that at each wattage level traffic operations were safer under a two-luminaire system than they were under a one-luminaire system.

The results of the cost-effectiveness analysis of the levels of illumination at the study site are presented in Table 3. The system that had the lowest annual accident cost was the two 200-watt HPS luminaire system as would be expected from the previous discussion of the measures of safety-effectiveness. In addition, this system had the lowest total annual cost and therefore it was the most cost-effective lighting system at the study site. The total annual costs of the one 100-watt, two 100-watt, and two 400-watt HPS luminaire systems were higher than the cost of no lighting system.

TABLE 3 Total Annual Costs of Six Levels of Illumination and Condition of No Lighting at Study Site

Lighting System	Annual Installation and Maintenance Cost ($)[a]	Annual Accident Rate[b] (no./yr)	Annual Accident Cost[b,c]	Total Annual Cost ($)
None	0	0.263	3,200	3,200
One 100-watt	162.60	0.279	3,397	3,560
Two 100-watt	325.20	0.241	2,929	3,255
One 200-watt	185.88	0.243	2,957	3,145
Two 200-watt	371.76	0.227	2,763	3,145
One 400-watt	226.44	0.240	2,919	3,145
Two 400-watt	452.88	0.234	2,847	3,300

[a]District-owned and maintained system, dusk-to-dawn lighting, steel standards, 40-ft mounting height, and underground wiring.
[b]On the uncontrolled approaches.
[c]Based on 1980 accident costs of the National Safety Council ($170,000 per fatal accident; $6,700 per nonfatal injury accident; and $980 per property-damage-only accident).

The results of the cost-effectiveness analysis conducted over the range of ADT levels representative of those found at unchannelized intersections of rural two-lane highways in Nebraska are shown in Figure 1. These results indicate that for main highway ADTs lower than 3,250 vpd a condition of no lighting system results in the lowest total annual costs. Therefore, no lighting system is warranted at rural, four-legged, unchannelized intersections of two-lane highways with main highway ADT less than 3,250 vpd. However, for main highway ADT greater than 3,750 vpd a two 200-watt HPS luminaire system is warranted.

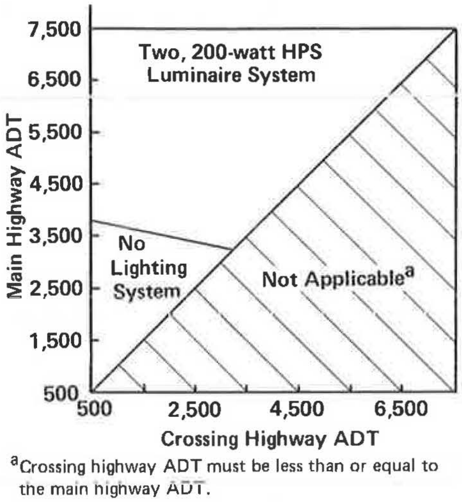

FIGURE 1 Most cost-effective lighting systems at unchannelized intersections of rural two-lane highways in Nebraska.

CONCLUSIONS

Based on the results of this research, the following conclusions were reached on the safety effects of lighting on traffic operations on uncontrolled approaches to unchannelized, two-way stop-sign-controlled intersections of rural two-lane highways.

1. For a given luminaire wattage traffic operations are safer with a two-luminaire system than with a one-luminaire system.
2. The safest traffic operations were observed with a two 200-watt HPS luminaire system.
3. Traffic operations with 100-watt HPS luminaire systems were not safer than those with no lighting system.

The results of the cost-effectiveness evaluation indicated that the most cost-effective lighting system was the two 200-watt HPS luminaire system, but it was only warranted at intersections with main highway ADT greater than 3,750 vpd. No lighting system was warranted at intersections with main highway ADT less than 3,250 vpd.

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Using Computer-Generated Pictures to Evaluate Headlamp Beam Patterns

EUGENE I. FARBER and VIVEK D. BHISE

ABSTRACT

A computer graphics system for generating pictures showing a driver's view of the roadway at night, as illuminated by a particular headlamp system, is described. These night scene images realistically depict the brightness patterns on the road surface and the illumination of pedestrians and lane lines produced by the headlamps. Veiling glare and backlighting from opposing headlamps can also be shown. The system was developed to permit comparative evaluations of existing and "drawing board" beam patterns for appearance, subjective qualities, and the visibility of various elements in the driver's field of view. The system also provides a direct pictorial representation of the numerical results obtained from various visibility models. The development of the computer graphics system is described in the context of other analytical approaches to headlamp evaluation that have been developed during the last 10 years. The pictures are pure analytical in origin; they are generated from candlepower tables representing the intensity distribution of a given headlamp and specifications of the shape, location, and reflectance of elements in the visual field. The basic algorithm for generating the pictures, including the geometric and photometric calculations, is discussed in general terms. Pictures representing five different European and U.S. tungsten and halogen systems are presented and compared with regard to appearance, aesthetics, and visibility. Differences between the systems are apparent, and the pictures are in accord with the results of analytical calculations of visibility. The pictures illustrate the complex trade-offs required in beam pattern design and help demonstrate that some important aspects of headlamp performance may not be apparent to the casual observer.

Figure 1 is a computer-generated representation of a driver's eye view of a night highway scene as illuminated by a particular headlamp system--tungsten 4000s in this case. The picture was created by a program called IVIEW developed by the Ford Motor Company Safety Research Office. IVIEW was written to supplement other computer-based analytical approaches to headlamp evaluation that have been developed at Ford during the last 10 years. The picture allows proposed beam patterns to be previewed for appearance and subjective qualities while still on the drawing board. Obviously, this is a method that can be applied equally well to fixed lighting systems. Before describing the IVIEW system, it will be useful to describe the context in which it was developed.

BACKGROUND

Researchers at the Safety Research Office at Ford Motor Company have been working on various headlighting models since the early 1970s. A description

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NOTE: The printed reproductions of the computer graphics images accompanying the text have less resolution and dynamic range than the photographic originals from which they were made. The originals were direct color Polaroid prints or 35 mm slides of the image that appears on the computer graphics screen. Readers interested in seeing an example of an original image should contact Eugene Farber at (313) 322-1972.