Steady-Burn Lights in Highway Work Zones: Further Results of Study in Ohio

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Examined in this paper is the effect of steady-burn lights on driver behavior in divided and undivided highways with horizontal and vertical curves; and with and without external lighting, entrance and exit ramps, tapered sections of lane closures, and median crossovers. The study was based on an examination of the driving behavior of a sample of driver subjects who were asked to drive an instrumented automobile in several highway work zones during the day, during the night when steady-burn lights were placed on drums, and during the night when steady-burn lights were removed. The effect of steady-burn lights on the lane-changing behavior of motorists in advance of the tapered sections was determined by recording traffic volume at three to four locations in each travel lane before the taper. The results showed that steady-burn lights had little effect, if any, on driver behavior in highway work zones. It appears that the high-intensity sheeting on drums and the flashing arrow panel had a powerful effect on drivers, thus leaving the steady-burn lights without any practical value in the work zones. It is concluded that steady-burn lights are not required for traffic control when drums with high intensity sheeting and flashing arrow panel are used as channelizing devices in these highway facilities.

A highway construction work zone generally creates conflicts between vehicular traffic and work activity, which leads to a reduction in the number of traffic lanes and to traffic conditions that violate motorist expectations. The work activity is also frequently compromised and worker movements restricted.

In Ohio, plastic drums are generally used for traffic control in highway construction work zones. These drums are required to have Type *G* (also known as high-intensity) reflective sheeting and Type *C* steady-burn lights for lane closures at night. A previous study (*1*,*2*) examined the effects of steady-burn lights in tangent sections of several rural, unlighted (e.g., without any external illumination), four-lane divided highways, including an Interstate freeway under dry, rainy, and foggy weather conditions. The study found that steady-burn lights have little effect, if any, on speed, acceleration noise, lateral placement and weaving when drums with high-intensity sheeting are used as channelizing devices in tangent sections of rural divided highways. No erratic driver behavior was observed when steady-burn lights were absent on drums. The study recommended that the use of steady-burn lights in tangent sections of construction work zones in rural divided highways, including freeways, be discontinued in the future.

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Further, the effects of steady-burn lights in curved, lighted, unlighted, and tapered sections, ramps, and median crossovers in work zones were examined during field tests in Ohio. The objective of the study was to determine whether steady-burn lights are needed in divided and undivided highways with horizontal and vertical curves, with and without external lighting, entrance and exit ramps, tapered sections of lane closures, and median crossovers. The following sections describe the research method, data collection, and results of the study.

RESEARCH APPROACH

An instrumented automobile was used to collect the required data in several highway work zones. Driver subjects were asked to drive the automobile during the day, at night when steady-burn lights were placed on drums, and at night when steady-burn lights were removed. A total of 321 runs were made, representing a sample of 107 driver subjects. The driver subjects did not drive the automobile in the same sequence. Some of the subjects started their first drive in daytime, some at nighttime with steady-burn lights on drums, and some at nighttime without steady-burn lights. The percentage of subjects with first drive in each period is shown in Figure 1. The driver subjects were not told of the presence or absence of steady-burn lights on the drums. None of the subjects were told why they were being asked to drive the automobile. Each subject was asked to drive the instrumented automobile as he or she would drive any other automobile. The tests without steady-burn lights were performed by covering the lights with black plastic bags. The bagging of steady-burn lights had the effect of having no steady-burn lights on the drums.

Right and left lane closures were examined separately. In addition, both right and left curves were examined by collecting data in both directions, as described in the later sections of this paper. The measures of effectiveness employed in the study consisted of

1. Speed: The speed parameters were the mean and variance. The speed of the vehicle for each test was measured continuously at 1.0-sec intervals. A large increase in mean speed or variance caused by the absence of steady-burn lights may indicate the existence of an abnormal and unsafe condition in the work zone. Similarly, a large decrease in mean speed may lead to delay and congestion which, under some circumstances, could create a hazardous condition, especially if the variance increased.

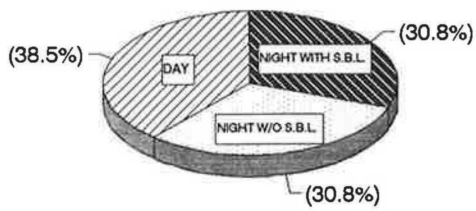

FIGURE 1 Sequence of starting first drive.

2. Lateral placement: When drivers see and approach an object near the path of the vehicle, they tend to move the vehicle away from the object. In this study, the lateral distance between the vehicle and the longitudinal pavement marking was measured at ½-sec intervals. Large variations in lateral placement may indicate driver confusion or an unsafe condition.

3. Acceleration noise: The standard deviation of acceleration is called acceleration noise and is used to determine the smoothness of the trip. A high acceleration noise normally represents a "rough" trip and a low acceleration noise a "smooth" trip. Acceleration noise was calculated for each trip based on the vehicular speeds recorded continuously at 1.0-sec intervals.

4. Weaving: Weaving is defined as the rate of change in lateral displacement per unit time. If X_i and X_{i-1} are lateral placements of the vehicle at times t_i and t_{i-1} respectively, then the average weaving over the trip period T consisting of n intervals is expressed as

$$W_{\text{avg}} = \sum [ABS\,(X_i - X_{i-1})]/n$$

where

W = weaving,
ABS = absolute value,
X_i = lateral placement of the vehicle at times t_i(in this study, t was measured in units of ½ sec),
X_{i-1} = lateral placement of the vehicle at times t_{i-1}, and
n = number of intervals.

A low value of weaving would indicate a "smooth" trip and a high value would indicate a "rough" trip.

5. Traffic conflict: A traffic conflict is defined as an unusual or drastic action by a driver while driving through a highway construction work zone. Evidence of an unusual or drastic action as a direct result of the absence of steady-burn lights would indicate a potentially dangerous situation.

6. Lane change before closure: Drivers in the lane to be closed are expected to change the lane long before they reach the taper or at least before the beginning of the taper. The effect of steady-burn lights on the lane-changing behavior of drivers was determined by recording traffic volume at three to four locations in each travel lane upstream of the taper during the three study periods (day, night with steady-burn lights, and night without steady-burn lights).

7. Driver preference: Immediately after the completion of the three tests, each driver was asked to fill out a questionnaire describing age, sex, vision, education, driving experience, mileage typically driven in a year, and involvement in any accident in a highway work zone in the past. Each driver subject was asked if there was any change or difference in the work zone between the two night tests. If the subject noticed the absence of steady-burn lights during the night tests, a subjective evaluation of the steady-burn lights was conducted through another questionnaire. The subjects who did not notice the absence of steady-burn lights were not given the second questionnaire.

DATA COLLECTION

The test automobile was equipped with a distance measuring instrument that continuously recorded the distance traveled by the automobile at 1.0-sec intervals and downloaded it into a portable personal computer. A Hi-8mm video camera was installed on the automobile roof and a 9-in. color monitor in the rear interior of the automobile. The video camera was enclosed in an environmental chamber consisting of a wiper, defogger, heater, and blower that allowed video photography under adverse weather conditions. The camera provided an approximately 6-ft-wide view of the roadway, including a partial view of the front exterior of the automobile. The automobile was equipped with extra lights underneath the front bumper so that a limited amount of illumination could be directed to the pavement markings for better photography at night. These lights, however, provided no extra illumination onto the driver's path. In addition, a flashlight bulb was connected to the automobile's rear brake system and installed in the rear interior to record braking, if any, during the test drive. None of the driver subjects were aware of the existence of the electric bulb. All highway construction work zones conformed to Ohio Department of Transportation (ODOT) specifications. Drums with high-intensity sheeting were placed at 100- to 120-ft spacing, which was reduced to 50 ft at tapered sections. The drums were generally placed 1 to 2 ft inside the lane closed for construction. The lane width in all sites was standard 12 ft. As required by ODOT specifications, a flashing arrow panel operated at the beginning of the taper. The length of the taper conformed to ODOT specifications. The contractor generally maintained the steady-burn lights in good condition. The conditions of the drums and the pavement markings varied from poor and dirty at some locations to good at others. A brief description of the characteristics of the work zones is provided in the following paragraphs.

Interstate 275 (Hamilton County)

This is a rural, six-lane divided highway (three lanes in each direction) with no external lighting and with right-lane closure in each direction. The posted speed limit was 65 mph. The highway had a degree of curvature of 2 deg. 45 min. 00 sec. and a grade of 3.0 percent. The average widths of the left and right shoulders were 9 to 10 ft and of the grass median 41 ft. Data were also collected at an entrance ramp and an exit ramp with right-lane closures. The posted speed limit in the ramps was 35 mph.

Interstate 74 (Hamilton County)

This is a suburban, four-lane divided highway (two lanes in each direction) with a 74-ft-wide (average) grass median. The highway work zones in each direction consisted of both lighted and unlighted roadways. The posted speed limit was 55 mph and the highway sections had right-lane closures in each direction. The maximum degree of curvature on the highway was 3 deg. 30 min. 00 sec. and the maximum grade was 3 percent. The widths of the left and right shoulders were 11 ft in the northbound direction and 7 to 11 ft in the southbound direction. Data were also collected at an entrance ramp and an exit ramp with right-lane closures. The posted speed limit in the ramps was 35 mph.

US-52 (Scioto County)

The section of US-52, where data were collected in both directions, is a rural, four-lane divided highway (two lanes in each direction). The posted speed limit was 55 mph. The data were collected both under lighted and unlighted conditions by switching the street lamps on or off as necessary. The work zone consisted of a right-lane closure in one direction and a left-lane closure in the other. The highway had a maximum degree of curvature of 3 deg 38 min. 33 sec. and a maximum grade of 1.0 percent.

US-27 (Hamilton County)

The data were collected in both directions of US-27 (just north of I-275), which is a suburban, four-lane undivided highway (two lanes in each direction) with no external lighting. The posted speed limit was 55 mph. The highway had right-lane closure in each direction. The degree of curvature was 4 deg. 00 min. 00 sec. and the grade was 3 percent. The average widths of the left and right shoulders were 4 to 8 ft.

SR-16 (Licking County)

This is a rural, unlighted four-lane (two lanes in each direction) divided highway with the posted speed limit of 55 mph. The data at this work zone were collected in a median crossover with a reverse curve (a left-lane closure followed by a right-lane closure). The degree of curvature for each curve was 3 deg. 00 min. 00 sec. The width of the left and right shoulders was 8 to 10 ft and the median width was approximately 40 ft.

The study grouped the driver subjects according to their ages as follows:

- Under 30 years,
- 31 to 45 years,
- 46 to 60 years, and
- 61 to 75 years.

The proportion of driver subjects in each age group is shown in Figure 2. A list of the test sites and the number of runs is shown in Table 1.

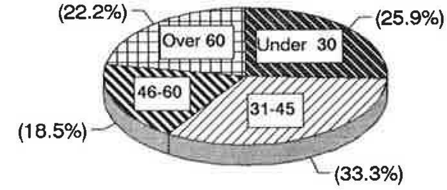

FIGURE 2 Age group of drivers.

DATA ANALYSIS AND RESULTS

In general, the speed and lateral placement data for each subject at each site were collected from the end of the tapered section to the end of the curved section of the work zone, with the total length of up to ¾ mi. The mean vehicular speeds for each period at each site are presented graphically in Figure 3. Because the geometric and traffic conditions at each site were different, the speeds at different sites are not comparable. For example, the daytime mean speed at I-275 (eastbound) was 66.4 mph, and at US-27 (northbound) was 47.7 mph. The analysis showed that the nighttime speeds were generally lower than the daytime speeds. However, the nighttime speed varied between different sites, with no clear indication of any pattern of high or low speeds when steady-burn lights were absent on the drums. A past study (*3*) has indicated that a speed difference of 4 mph or less is not of practical significance. In this study, no difference of greater than 4 mph was found at any site between the two night periods, with and without steady-burn lights. However, a few differences greater than 4 mph were found between the day and night speeds.

The reference line for measurement of lateral placement was generally the pavement marking closest to the camera. The average lateral placements for each period at each work zone are presented in Figure 4. These data indicate that lateral placements were slightly higher or lower at the sites when steady-burn lights were absent on drums, but provided no clear pattern on the effects of the steady-burn lights.

The acceleration noise and weaving for each period at each work zone are presented in Figures 5 and 6, respectively. In general, acceleration noises during daytime or on ramps were higher than those during other periods or at other facilities. However, no specific pattern of increase in acceleration noise existed on any particular type of lane closure or lighting condition.

In order to determine if the differences in the means between any two study periods were significant, several hypotheses were tested for each of the first four measures of effectiveness (MOEs) (speed, lateral placement, acceleration noise, and weaving) by performing paired *t*-tests at 5 percent level of significance. The SAS and STATGRAPHICS software were used to perform the tests. The paired *t*-tests examined the null hypothesis that the speed, lateral placement, acceleration noise, or weaving during any two of the three test periods (day, night with steady-burn lights, or night without steady-burn lights) remains unchanged. For example, the speed of each individual driver was compared for each of the three periods by taking the difference in speeds for two periods at a time. In this way, any difference in speed between day and night and also between the two nighttime periods for the same driver can be determined. The tests were first performed separately for each site. The data for the two directions of the same highway were then combined and further testing of the hypotheses was performed. For example, the

TABLE 1 List of Sites

No.	SITE		NUMBER OF RUNS	SPEED LIMIT (MPH)
1.	I-275	WB[a]	18	65
2.	I-275	EB[b]	18	65
3.	I-74	EB_1[c]	18	55
4.	I-74	EB_2[d]	18	55
5.	I-74	WB_2	18	55
6.	I-74	WB_1	18	55
7.	US 52	EB_1	15	55
8.	US 52	EB_2	30	55
9.	US 52	WB_2	30	55
10.	US 52	WB_1	15	55
11.	US 27	NB[e]	18	55
12.	US 27	SB[f]	18	55
13.	I-275	EX[g]	18	35
14.	I-275	EN[h]	18	35
15.	I-74	EX	18	35
16.	I-74	EN	18	35
17.	SR 16	CO[i]	15	55

[a]*West Bound* [b]*East Bound*
[c]*Lighted roadway* [d]*Unlighted roadway*
[e]*North Bound* [f]*South Bound*
[g]*Exit ramp* [h]*Entrance ramp*
[i]*Crossover*

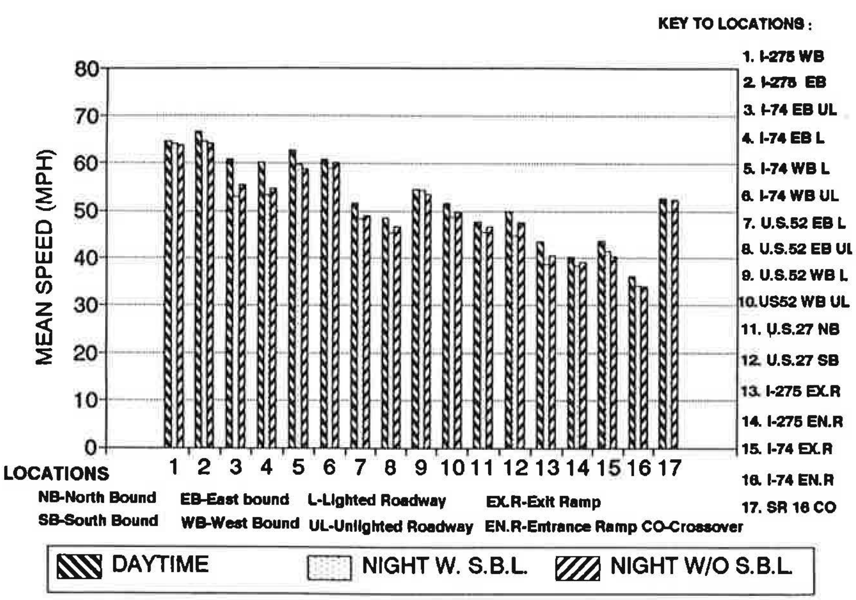

FIGURE 3 Mean speed.

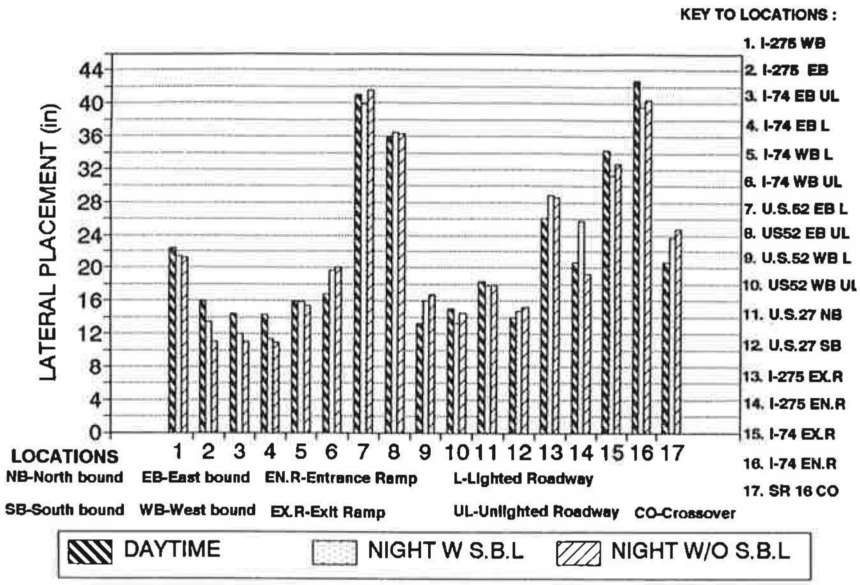

FIGURE 4 Mean lateral placement.

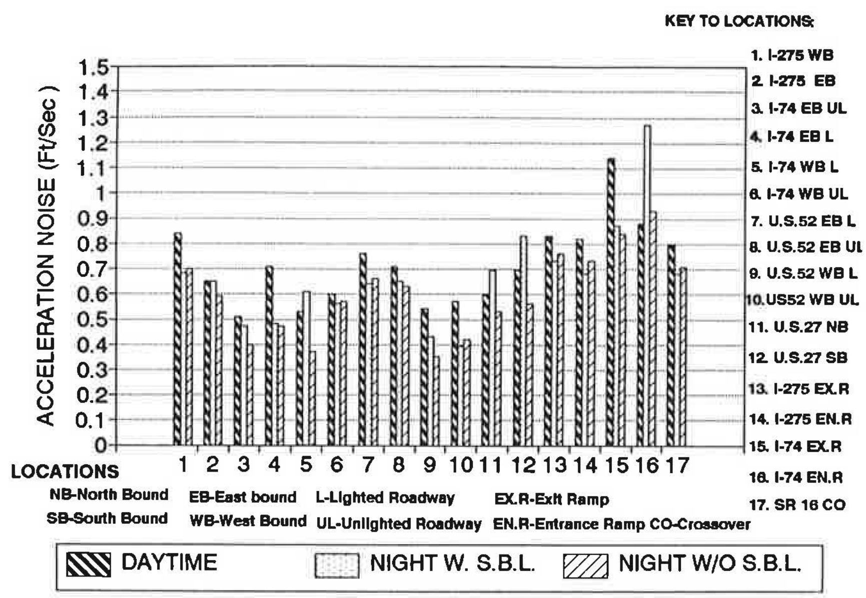

FIGURE 5 Mean acceleration noise.

speed data for west- and eastbound I-275 were combined because both directions had right-lane closures and the speed limits were the same. Finally, paired *t*-tests were performed by combining the data for all sites.

Further statistical analysis of the data was done by conducting one-way analysis of variance. For example, the speeds for the two nighttime periods were examined by taking the daytime speed as a control value. In other words, the differences between daytime and nighttime with steady-burn lights, and between daytime and nighttime without steady-burn lights were calculated and testing was conducted to determine whether these two speed differences were significant.

In general, the null hypotheses were accepted, indicating that the MOEs (speed, lateral placement, acceleration noise, or weaving) during the three periods were not significantly different. Analysis showed that steady-burn lights had no impact on the MOEs during lane closure at night. In a few cases, the null hypotheses between day and night tests (either with or without steady-burn lights) were rejected. However, there was no significant difference in the MOEs between the two night periods (with and without steady-burn lights on drums), indicating that the presence or absence of steady-burn lights had no impact on the MOEs. When tests were performed for weaving, a few null hypotheses between the two nighttime periods were rejected; however, the differences were too small to be of any practical importance.

In summary, the results of the study showed that there was no impact on the means and variances of speed, lateral place-

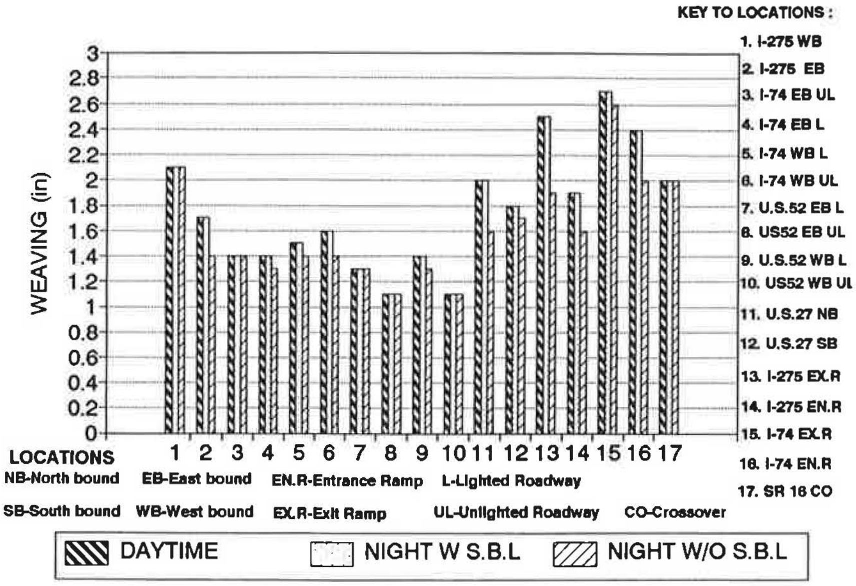

FIGURE 6 Mean weaving.

ment, acceleration noise, and weaving during the absence of steady-burn lights on drums with high-intensity reflective sheeting.

Traffic Conflict

The tests showed that a small number of subjects applied their brakes when they encountered slow or merging traffic. The absence of steady-burn lights on drums did not cause any unusual or drastic action on the part of the subjects.

Lane Change Before Closure

Traffic volume counts recorded in advance of the tapered sections were analyzed to determine the effects of steady-burn lights on the lane-changing behavior of motorists before the beginning of the tapered section. The highway section in advance of the taper was subdivided into three to four subsections (an example is shown in Figure 7). The analysis consisted of comparing the proportion of traffic volume changing lanes (from the lane to be closed to the open lane) and by testing the null hypothesis that the proportion of traffic volume in each subsection of the highway remained unchanged during the three periods. A rejection of the null hypothesis would indicate that the lane-changing behavior had been affected during the period under study. Z-tests were performed separately for each site to test the hypotheses. The results showed that there were some significant differences in the proportion of traffic volume during daytime and nighttime, either with or without steady-burn lights. However, the null hypotheses during the two nighttime periods were accepted, indicating that the proportions of traffic within each subsection were not significantly different during the two night periods. It showed that steady-burn lights had no effect on the lane-changing behavior of motorists at night.

Driver Preference

Among the 27 subjects who responded to the question, 9 (33.3 percent) noticed the absence of steady-burn lights during their drives. Seven of the 9 subjects were in the "under 30 years"

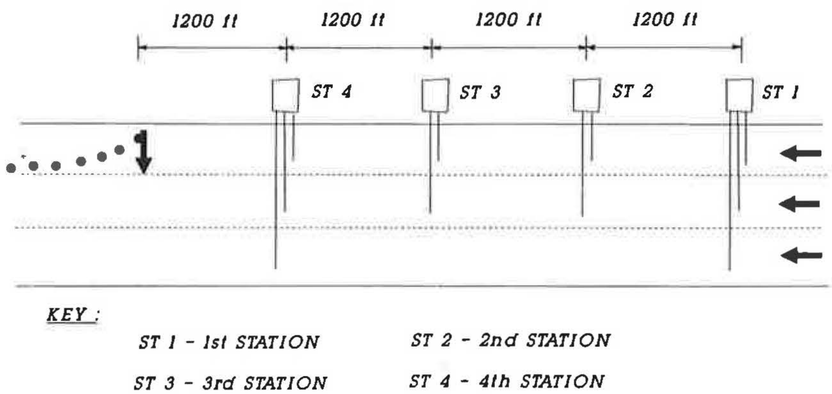

FIGURE 7 Traffic counting on westbound I-275.

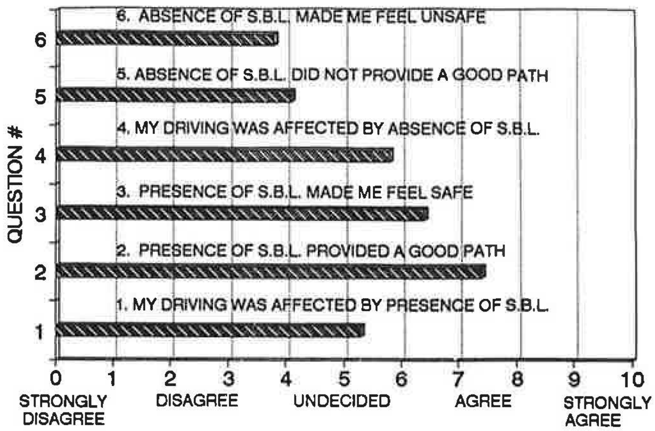

FIGURE 8 Results of driver responses.

age category, perhaps indicating that younger drivers were either sensitive to the change or curious about the experiments. The subjects who noticed the absence of steady-burn lights were asked six more questions, among which the first three were related to the presence of steady-burn lights, and the remaining three to the absence of steady-burn lights. Their responses on the following scale of 1 to 10 are shown in Figure 8.

0	1	2	3	4	5	6	7	8	9	10
Strongly Disagree		Disagree			Undecided		Agree			Strongly Agree

The results showed that the subjects did not have any strong opinions on the absence of steady-burn lights and did not feel unsafe because of the absence of steady-burn lights on drums.

CONCLUSIONS

Examined in this study is the effectiveness of steady-burn lights on drums with high-intensity sheeting in divided and undivided highways, including curved, lighted, unlighted, and tapered sections, and ramps and crossovers. The results showed that steady-burn lights had little, if any, effect on driver behavior. The statistical analysis repeatedly showed that the means and variances of speed, lateral placement, acceleration noise, and weaving were not significantly different when steady-burn lights were absent on the drums. Similarly, the proportions of traffic volume in different subsections of the highways in advance of the taper were not different during the absence of steady-burn lights, indicating that steady-burn lights had no effect on the lane-changing behavior of motorists at night. It appears that the high-intensity sheeting on drums and the flashing arrow panel in the beginning of taper had a powerful effect on the motorists, thus leaving the steady-burn lights without any practical value in the work zones. None of the drivers showed any erratic behavior when steady-burn lights were absent on drums. Some driver subjects noticed the absence of steady-burn lights during the tests and even their responses indicated that steady-burn lights had little effect on driving behavior or safety in the work zone.

In conclusion, the study has shown that steady-burn lights are not required in curved, lighted, unlighted, and tapered sections of highway work zones, including ramps and crossovers, when drums with high-intensity sheeting and flashing arrow panel are used as channelizing devices. It is recommended that the use of steady-burn lights in these highway facilities be discontinued in the future.

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