Effect of Pavement Markers On Nighttime Crashes in Georgia

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Abstract

During 1976-1978, the Georgia Department of Transportation installed reflectorized pavement markers on the centerlines of nearly 700 curves in Georgia which had horizontal curvature in excess of six degrees. Nighttime crashes were reduced by about 20 percent compared to daytime crashes at these sites subsequent to the installation of the markers. Nighttime single-vehicle crashes were reduced more than other nighttime crashes.

Previous work has established a strong positive association between the presence of horizontal curvature and the frequency of fatal or injury-producing single-vehicle crashes involving off-road fixed objects (1,2). These studies, which were based on Georgia crash data, have also shown that the sharper the curve the greater the increase in crash frequency. Improvements should be concentrated on road sections with horizontal curvature in excess of six degrees, the studies recommended. Subsequent studies of fatal rollover crashes, conducted in Georgia and New Mexico, have supported these recommendations (3,4).

Prompted by these research findings, the Georgia Department of Transportion installed reflectorized pavement markers on the centerlines of nearly all curves in Georgia which had horizontal curvature in excess of six degrees. At some of these locations, additional devices such as warning signs and chevron markers were put in place during the same three-year time period between 1976 and 1978.

This paper presents an evaluation of the effectiveness of these modifications in reducing nighttime crashes.

Data

From a preliminary list of 740 improved curves, 78 were discarded because of missing data. For the remaining 662 sections the following data were available:

Curve location

Curve length

Degree of curve

Year of modification

Average daily traffic by year

Crash frequency by year (1975-1980), by type (single vehicle or other) and by time of day (day or night; day: 6 am - 5:59 pm)

By definition, curve length was extended for the purpose of crash data collection about 200 feet (0.04 mile) in both directions beyond the actual curve. This was done because previous work (1-4) had shown that curve-related single-vehicle crashes often take place beyond the end points of curves.

Method

Reflectorized markers are visible mostly at night and, therefore, if they are effective in reducing crashes at all they would be expected to reduce nighttime crashes and, in particular, the frequency of nighttime crashes in comparison to daytime crashes.

To test for a change in the relative frequency of nighttime crashes subsequent to the modifications, the crashes were classified by year of modification (1975-1977), year of crash (1975-1980), and time of crash (day or night). The resulting 3x6x2 table was collapsed by grouping crashes before and after year of modification to form a 3x2x2 table:

Year of Crash Relative to Year of Modification

Year of Modification	Time of Day	Before	After
1975	Night	n_{111}	n_{112}
	Day	n_{121}	n_{122}
1976	Night	n_{211}	n_{212}
	Day	n_{221}	n_{222}
1977	Night	n_{311}	n_{312}
	Day	n_{321}	n_{322}

(Crashes that occurred in the year of modification were excluded from the table.)

If reflectorized markers made no difference at night, the frequency of nighttime crashes after the modification would be estimated using the formula

$$\hat{n}_{k12} = n_{k22} \frac{n_{k11}}{n_{k21}} , \quad k = 1, 2, 3 \tag{1}$$

The equality of the estimated and observed crash frequencies was tested using the Mantel-Haenszel procedure (5). The test statistic was

$$M^2 = \frac{(\left| \Sigma (n_{k12} - \hat{n}_{k12}) \right| -0.5)^2}{\Sigma V_k} \tag{2}$$

where

$$V_k = \frac{n_{k+1} n_{k+2} n_{k1+} n_{k2+}}{n_{k++}^2 (n_{k++} -1)} \tag{3}$$

is the variance estimate for n_{k12}. (The plus sign in formula (3) means that the corresponding suffix is summed over its range, e.g., $n_{k+1} = n_{k11} + n_{k21}$.) In the absence of a change in the nighttime to daytime crash frequency ratio, the distribution of the test statistic is χ^2 with one degree of freedom. It should be noted that the Mantel-Haenszel procedure was valid because the interaction between time of day and year of crash relative to year of modification was constant over the three modification years. The constancy of this interaction was tested by testing for the absence of a three-way interaction in the table (cf. p.146-148, (5)). The latter test consists of fitting to the data a loglinear model that includes all two-way interactions but excludes the three-way interactions, and then testing the fit of the model to the data. Since this model fit the data, the three-way interactions were zero.

The same technique was also used to examine the effect of curvature and average daily traffic on the effect of the improvements.

Results

A total of 614 crashes occurred along the highway sections during the study period, and in 84 instances there were two or more crashes during a given year. Thirty-six percent (223) of the crashes occurred before the road sections were modified, and 64 percent (391) occurred after modification. For about 68 percent of the study sites, no crash was reported for the six-year observation period.

Table 1 displays the observed crash frequencies before and after the year of modification by year of modification and time of day. These data were fitted by a loglinear model which included all but the three-way interaction terms. The estimated frequencies are shown in parentheses. The fit of the model to the data was acceptable (Freeman-Tukey Chi Square 4.46, 2df, $p \geq 0.10$). The hypothesis that there is no interaction between time of day and year of crash relative to year of modification was tested and rejected using the Mantel-Haenszel procedure (Mantel-Haenszel Chi Square 50.97, 1df, $p \leq 0.001$).

Table 1

Observed (Estimated) Annual Crash Frequency
on Modified Road Sections in Georgia during 1975-1980;
Distribution by Year of Modification,
Crash Year Relative to Year of Modification and Time of Day

Year of Modification[1]	Time of Day	Year of Crash Relative to Year of Modification: Before	After
1976	Night	12 (10.51)	11.3 (11.6)
	Day	16 (17.49)	22.3 (21.9)
1977	Night	22 (20.0)	20.7 (22.0)
	Day	28.5 (30.5)	39.3 (38.0)
1978	Night	10.7 (12.5)	17.0 (14.2)
	Day	20.7 (18.8)	21.5 (24.3)

(1) The road sections modified during the three years differed from year to year in ADT curvature, etc. (cf. Table A-2).

The reduction in nighttime crashes was then estimated for sites modified in each year by the formula $(n_{k12} - \hat{n}_{k12})/\hat{n}_{k12}$ (cf formula 1). It was found that nighttime crashes were reduced by 33 percent for sites modified in 1976, and by 32 percent for sites modified in year 1977. However, nighttime crashes increased by 53 percent for sites modified in 1978. The overall reduction in nighttime crashes was estimated by the formula

$$\frac{\Sigma n_{k12} - \Sigma n_{k12}}{\Sigma n_{k12}} \qquad (4)$$

and was found to be 22 percent. These results are shown in Figure 1.

The distribution of crash frequencies by year of crash, year of modification, and time of day was further examined to test for possible non-chance variation in the ratio of nighttime crashes divided by daytime crashes over the time periods during which the sites were <u>not</u> modified. It was found that conditionally on the year of modification the ratio of nighttime crashes divided by daytime crashes was independent of the calendar year of the crash both before the modifications ($p \geq 0.5$, Freeman Tukey Chi Square 2.45 4df) and after the modifications were put in place ($p \geq 0.50$, Freeman-Tukey Chi Square 6.82, 8df). In other words, it was found that this ratio changed no more from year to year during either the pre-modification years or the post-modification years than could be explained in terms of chance fluctuations alone. This result confirmed the stability of the test ratio in the absence of site modifications.

The distribution of crash frequencies was further analyzed in terms of horizontal curvature and average daily traffic. This was done by sorting crashes in the three-way table according to curvature (high and low) and average daily traffic (high and low). The resulting two four-way tables were analysed in the same manner as described above. The results showed that the effect of the improvements was independent of both the curvature and the volume of traffic at the site. Note, however, that all study sites had curvature in excess of six degrees; consequently, the present results provide no information on the efficacy of the modification when applied to sections with lower curvature.

Finally, the differential effect of the improvements on single-vehicle and other nighttime crashes was tested using the Mantel-Haenszel procedure to analyze the distribution of nighttime crashes by year of modification, year of crash relative to year of modification, and type of crash. It was found that single-vehicle crashes were affected more than other crashes at night (Mantel-Haenszel chi square 9.41, 1df, $p \leq 0.01$). The reductions in single-vehicle crashes were 37 percent for sites modified in 1976, and eight percent for sites modified in 1977. There was a 12 percent increase for the 1978 modifications. The overall reduction in single-vehicle nighttime crashes compared to other night crashes, estimated by formula (4), was about 12 percent.

Summary statistics on curve length, curvature, average daily traffic, and crash rates are presented in the Appendix (Tables A.1 and

A.2). It is clear from Table A.2 that the overall crash rates were not reduced in Georgia by the installation of the reflectorized pavement markers. However, in view of the large fluctuations in the crash rates for the whole of the Georgia state road system, shown in Table A.3, this is not surprising. Table A.4 displays the frequency of all crashes on Georgia public roads by crash type and time of day. These data show that the ratio of nighttime to daytime crashes increased about 10 percent from 1976 to 1980. During the same period, run-off-the-road crashes at night increased almost 20 percent more than other crashes at night.

Discussion

The use of retroreflective pavement markers has increased greatly in recent years, and markers are perceived favorably by highway engineers and the general public as an effective delineation treatment. Advantages claimed for markers over paint stripes include reduced maintenance and more positive all-weather, nighttime delineation. The markers have also been reported to be effective in delineating detours through construction zones (6).

Research based on human factors and traffic performance studies have shown that pavement markers are more effective than postmounted delineators on isolated horizontal curves (7). Researchers have also reported that highway sections along tangents or along winding sites with raised pavement marker centerlines have lower crash rates than those with painted centerlines. The results of the analyses were not as definitive for isolated horizontal curves (8).

A report of the National Cooperative Highway Research Program (9) recommended the use of raised pavement markers on the centerlines of hazardous horizontal curves, based on the finding that such markers influence lateral placement variance. Schwab and Capelle (10) recommended the use of markers in mountainous terrain or where climatic conditions cause restricted visibility. A study sponsored by the Federal Highway Administration (8) recommended that painted centerlines be replaced by raised pavement markers where a service life of five years or more is expected and the annual ADT exceeds 3,000 vehicles per day. Benefit-cost calculations based on the results of this research suggest that at horizontal curve locations the use of retroreflective markers can be justified at a lower threshold of ADT. However, because of the uncertainty associated with crash prediction, it was not possible precisely to define appropriate use guidelines for curved sections.

As a by-product of the present investigation it was found that the in-place survivability of raised pavement markers is inferior to the survivability of recessed pavement markers (11).

Summary and Recommendations

The research reported here investigated the effectiveness of reflectorized pavement markers installed on the centerlines of two-lane highways at horizontal curve sections with curvature in excess of six degrees. The principal findings of this study were:

1. Installation of reflectorized markers on the centerline of roadways with curvature of six or more degrees reduced the relative frequency of nighttime crashes in comparison to daytime crashes by about 22 percent.

2. Among nighttime crashes, single vehicle crashes were reduced by 12 percent more than other crashes.

3. Recessed pavement markers survived longer in field conditions (11) than raised pavement markers.

The present findings lend further support to earlier recommendations advocating the use of reflectorized pavement markers (the recessed variety) to reduce nighttime crashes on horizontal curves.

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A-1

Average Daily Traffic and Site Characteristics by Year of

Modification and Year of Crash

Mod Year		Num Sites	Avg Curvature[1]	Avg Length[2]	AVG ADT 1975	1976	1977	1978	1979	1980
1976	Num	35	9.86	0.23	2046	2256	2081	2104	2184	2263
	Std		5.13	0.05	2631	2549	2721	2646	2480	2493
1977	Num	412	10.19	0.20	1298	1306	1426	1449	1387	1270
	Std		3.91	0.09	1374	1273	1468	1590	1543	1403
1978	Num	250	9.83	0.20	1292	1294	1408	1350	1318	1353
	Std		3.73	0.08	1565	1650	1570	1526	1557	1667

CRASH RATES PER 100 MILLION VEHICLE MILES
BY YEAR OF MODIFICATION, YEAR OF CRASH AND CRASH TYPE

MOD YEAR	CRASH TYPE	YEAR 1975	1976	1977	1978	1979	1980
1976	ALL	471.4	309.8	594.4	553.4	673.9	442.5
	NIGHT	202.0	48.9	148.6	179.1	248.3	221.2
	SINGLE	74.4	53.9	69.1	39.3	81.1	67.4
	SV NIGHT	84.2	0.0	16.5	81.4	53.2	85.1
1977	ALL	121.6	127.4	149.7	117.8	148.8	147.2
	NIGHT	49.6	58.8	64.5	37.1	36.1	42.4
	SINGLE	74.4	53.9	69.1	39.3	81.1	67.4
	SV NIGHT	34.7	39.2	36.9	17.5	49.6	25.0
1978	ALL	120.7	123.7	132.7	137.2	170.8	126.5
	NIGHT	51.7	35.9	41.7	52.5	46.6	57.5
	SINGLE	56.0	51.9	37.9	64.6	73.7	30.7
	SV NIGHT	25.9	23.9	19.0	40.4	50.5	23.0

A.3

STATEWIDE CRASH AND TRAVEL DATA

	1975	1976	1977	1978	1979	1980
Number of Crashes on State Road System	70,341	81,363	89,596	74,528	76,551	82,092
Travel on State Road System, 10^6 veh. mi.	24,480	29,797	27,619	28,483	29,755	28,376
Crash Rates for State Road System,						
Crashes/10^8 vehicle mile	287.3	273.1	324.4	261.7	257.3	289.3

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Number of Crashes in Georgia by Type of Crash,
Time of Day and Year

Crash Type	Time of Day	Year 1976	1977	1978	1979	1980
Run off road	Day	12,656	13,939	14,073	14,779	13,941
	Night	9,410	10,446	10,474	11,715	11,961
Other	Day	110,016	118,073	123,448	121,152	109,747
	Night	21,765	22,854	24,156	25,152	23,545

Notes 1. The data are for all public road crashes in Georgia.

2. Night crashes include those occurring at dusk, dawn, dark (street light) and dark (no street light).

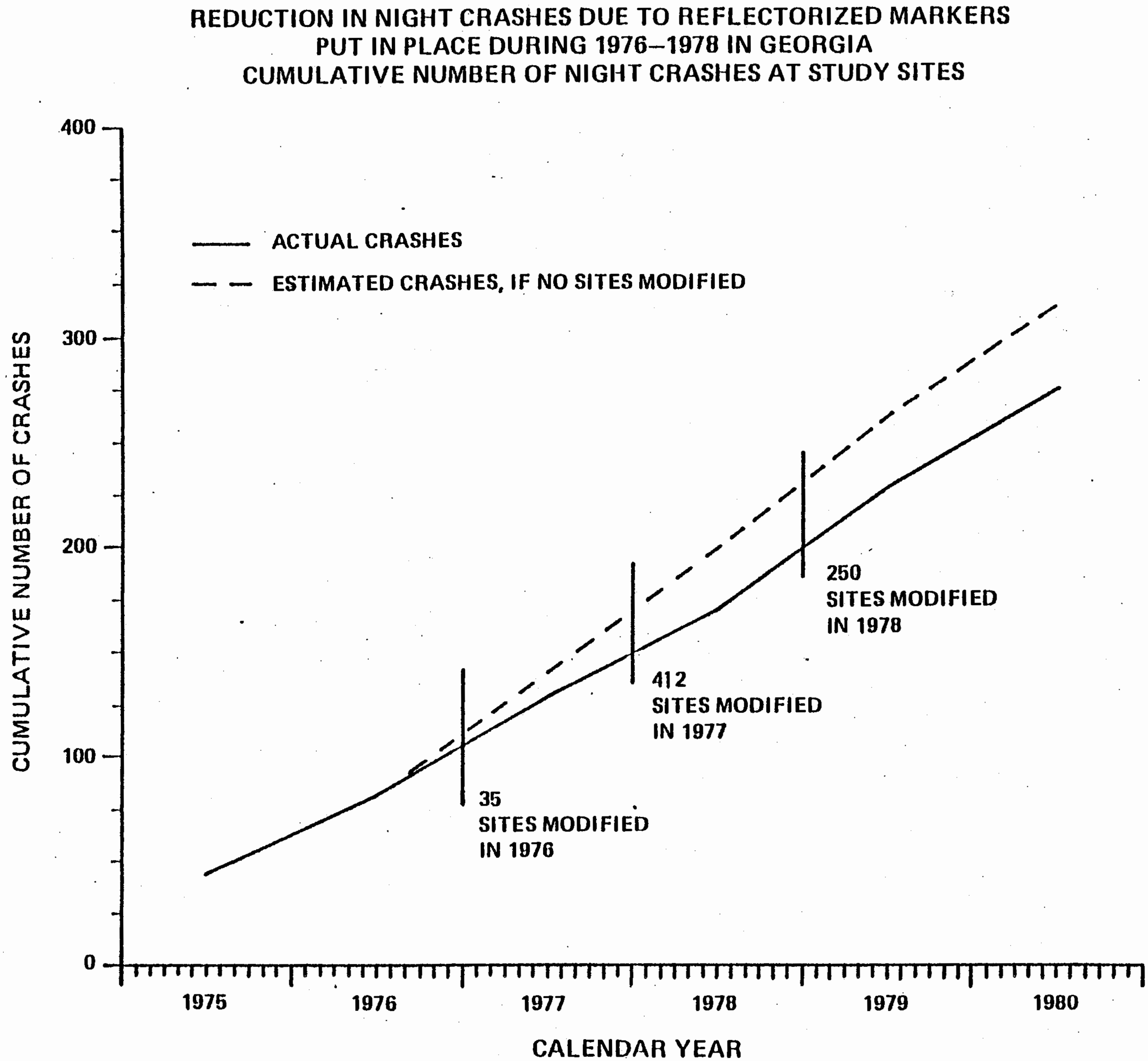

Figure 1. Cumulative effect of reflectorized markers on night crashes.