Project No. E-20-617

Project Director: Dr. Paul H. Wright

Sponsor: Insurance Institute for Highway Safety, Washington, DC

Type Agreement: Institute Project No. 6809, dated 3/23/81.

Award Period: From 4/1/81 To 12/31/81 Performance

Sponsor Amount: $18,440

Contracted through: GTRI/CDP

Title: A Study to Evaluate the Effectiveness of Traffic Countermeasures at Horizontal Curve Locations.

ADMINISTRATIVE DATA

OCA CONTACT Faith G. Costello

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Reports: See Deliverable Schedule

Security Classification: N/A

Defense Priority Rating: N/A

RESTRICTIONS

See Attached Supplemental Information Sheet for Additional Requirement

Travel: Foreign travel must have prior approval - Contact OCA in each case. Domestic travel requires sponsor approval where total will exceed greater of $500 or 125% of approved proposal budget category.

Equipment: Title vests with Sponsor; however, none proposed.

COMMENTS: *Draft copy due date, final to be submitted upon approval.
Date 7/11/83

Project Title: A Study to Evaluate the Effectiveness of Traffic Countermeasures at Horizontal Curve Locations

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Effective Termination Date: 12/31/81

Clearance of Accounting Charges: 12/31/81

Grant/Contract Closeout Actions Remaining:

- [ ] Final Invoice and Closing Documents
- [ ] Final Fiscal Report
- [ ] Final Report of Inventions
- [ ] Govt. Property Inventory & Related Certificate
- [ ] Classified Material Certificate
- [ ] Other

Project Director to send two (2) copies of Final Report to PPC, OCA Reports Coordinator. (Report has already been submitted to Sponsor).

Assigned to: Civil Engineering (School/Laboratory)

COPIES TO:

Administrative Coordinator  Research Security Services  EES Public Relations (2)
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FORM OCA 10:781
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 Transportation 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

<table>
<thead>
<tr>
<th>Year of Modification</th>
<th>Time of Day</th>
<th>Before</th>
<th>After</th>
</tr>
</thead>
<tbody>
<tr>
<td>1975</td>
<td>Night</td>
<td>(n_{111})</td>
<td>(n_{112})</td>
</tr>
<tr>
<td></td>
<td>Day</td>
<td>(n_{121})</td>
<td>(n_{122})</td>
</tr>
<tr>
<td>1976</td>
<td>Night</td>
<td>(n_{211})</td>
<td>(n_{212})</td>
</tr>
<tr>
<td></td>
<td>Day</td>
<td>(n_{221})</td>
<td>(n_{222})</td>
</tr>
<tr>
<td>1977</td>
<td>Night</td>
<td>(n_{311})</td>
<td>(n_{312})</td>
</tr>
<tr>
<td></td>
<td>Day</td>
<td>(n_{321})</td>
<td>(n_{322})</td>
</tr>
</tbody>
</table>

(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

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

(1)

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

\[
M^2 = \frac{\left( \sum (\hat{n}_{k12} - \hat{n}_{k12}) \right) - 0.5)^2}{\sum v_k}
\]  

(2)

where

\[
v_k = \frac{n_{k+1}n_{k+2}n_{k1+}n_{k2+}}{n_{k++}^2(n_{k++} - 1)}
\]  

(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 $\chi^2$ 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 > 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 < 0.001).

Table 1

<table>
<thead>
<tr>
<th>Year of Modification (1)</th>
<th>Time of Day</th>
<th>Year of Crash Relative to Year of Modification Before</th>
<th>After</th>
</tr>
</thead>
<tbody>
<tr>
<td>1976</td>
<td>Night</td>
<td>12 (10.51)</td>
<td>11.3 (11.6)</td>
</tr>
<tr>
<td></td>
<td>Day</td>
<td>16 (17.49)</td>
<td>22.3 (21.9)</td>
</tr>
<tr>
<td>1977</td>
<td>Night</td>
<td>22 (20.0)</td>
<td>20.7 (22.0)</td>
</tr>
<tr>
<td></td>
<td>Day</td>
<td>28.5 (30.5)</td>
<td>39.3 (38.0)</td>
</tr>
<tr>
<td>1978</td>
<td>Night</td>
<td>10.7 (12.5)</td>
<td>17.0 (14.2)</td>
</tr>
<tr>
<td></td>
<td>Day</td>
<td>20.7 (18.8)</td>
<td>21.5 (24.3)</td>
</tr>
</tbody>
</table>

(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

\[
\frac{\sum n_{k12} - \sum \hat{n}_{k12}}{\sum \hat{n}_{k12}} (4)
\]

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 not 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 \((p > 0.5,\) Freeman Tukey Chi Square 2.45 4df) and after the modifications were put in place \((p > 0.50,\) 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 analyzed 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 \( \chi^2 \) 9.41, 1 df, \( p \leq 0.01 \)). 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.
Acknowledgements

The writers gratefully acknowledge the cooperation and assistance of employees of the Georgia Department of Transportation, especially Mr. Archie Burnham, State Traffic and Safety Engineer, and Mr. Dick Graves, Chief Accident Analysis. The writers also appreciate the help of Miss Sandra Haga, Georgia Department of Administrative Services. The research was supported by the Insurance Institute for Highway Safety. The opinions, findings, and conclusions expressed in this paper are ours and do not necessarily reflect the views of the Insurance Institute for Highway Safety.
References


Average Daily Traffic and Site Characteristics by Year of Modification and Year of Crash

<table>
<thead>
<tr>
<th></th>
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<th></th>
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</thead>
<tbody>
<tr>
<td>1976 Num</td>
<td>35</td>
<td>9.86</td>
<td>0.23</td>
<td>2046</td>
<td>2256</td>
<td>2081</td>
<td>2104</td>
<td>2184</td>
<td>2263</td>
</tr>
<tr>
<td>Std</td>
<td></td>
<td>5.13</td>
<td>0.05</td>
<td>2631</td>
<td>2549</td>
<td>2721</td>
<td>2646</td>
<td>2480</td>
<td>2493</td>
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<tr>
<td>1977 Num</td>
<td>412</td>
<td>10.19</td>
<td>0.20</td>
<td>1298</td>
<td>1306</td>
<td>1426</td>
<td>1449</td>
<td>1387</td>
<td>1270</td>
</tr>
<tr>
<td>Std</td>
<td></td>
<td>3.91</td>
<td>0.09</td>
<td>1374</td>
<td>1273</td>
<td>1468</td>
<td>1590</td>
<td>1543</td>
<td>1403</td>
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<tr>
<td>1978 Num</td>
<td>250</td>
<td>9.83</td>
<td>0.20</td>
<td>1292</td>
<td>1294</td>
<td>1408</td>
<td>1350</td>
<td>1318</td>
<td>1353</td>
</tr>
<tr>
<td>Std</td>
<td></td>
<td>3.73</td>
<td>0.08</td>
<td>1565</td>
<td>1650</td>
<td>1570</td>
<td>1526</td>
<td>1557</td>
<td>1667</td>
</tr>
</tbody>
</table>
## CRASH RATES PER 100 MILLION VEHICLE MILES
### BY YEAR OF MODIFICATION, YEAR OF CRASH AND CRASH TYPE

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1976</td>
<td>ALL</td>
<td>471.4</td>
<td>309.8</td>
<td>594.4</td>
<td>553.4</td>
<td>673.9</td>
<td>442.5</td>
</tr>
<tr>
<td></td>
<td>NIGHT</td>
<td>202.0</td>
<td>48.9</td>
<td>148.6</td>
<td>179.1</td>
<td>248.3</td>
<td>221.2</td>
</tr>
<tr>
<td></td>
<td>SINGLE</td>
<td>74.4</td>
<td>53.9</td>
<td>69.1</td>
<td>39.3</td>
<td>81.1</td>
<td>67.4</td>
</tr>
<tr>
<td></td>
<td>SV NIGHT</td>
<td>84.2</td>
<td>0.0</td>
<td>16.5</td>
<td>81.4</td>
<td>53.2</td>
<td>85.1</td>
</tr>
<tr>
<td>1977</td>
<td>ALL</td>
<td>121.6</td>
<td>127.4</td>
<td>149.7</td>
<td>117.8</td>
<td>148.8</td>
<td>147.2</td>
</tr>
<tr>
<td></td>
<td>NIGHT</td>
<td>49.6</td>
<td>58.8</td>
<td>64.5</td>
<td>37.1</td>
<td>36.1</td>
<td>42.4</td>
</tr>
<tr>
<td></td>
<td>SINGLE</td>
<td>74.4</td>
<td>53.9</td>
<td>69.1</td>
<td>39.3</td>
<td>81.1</td>
<td>67.4</td>
</tr>
<tr>
<td></td>
<td>SV NIGHT</td>
<td>34.7</td>
<td>39.2</td>
<td>36.9</td>
<td>17.5</td>
<td>49.6</td>
<td>25.0</td>
</tr>
<tr>
<td>1978</td>
<td>ALL</td>
<td>120.7</td>
<td>123.7</td>
<td>132.7</td>
<td>137.2</td>
<td>170.8</td>
<td>126.5</td>
</tr>
<tr>
<td></td>
<td>NIGHT</td>
<td>51.7</td>
<td>35.9</td>
<td>41.7</td>
<td>52.5</td>
<td>46.6</td>
<td>57.5</td>
</tr>
<tr>
<td></td>
<td>SINGLE</td>
<td>56.0</td>
<td>51.9</td>
<td>37.9</td>
<td>64.6</td>
<td>73.7</td>
<td>30.7</td>
</tr>
<tr>
<td></td>
<td>SV NIGHT</td>
<td>25.9</td>
<td>23.9</td>
<td>19.0</td>
<td>40.4</td>
<td>50.5</td>
<td>23.0</td>
</tr>
</tbody>
</table>
### A.3

**STATEWIDE CRASH AND TRAVEL DATA**

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
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<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Crashes on State Road System</td>
<td>70,341</td>
<td>81,363</td>
<td>89,596</td>
<td>74,528</td>
<td>76,551</td>
<td>82,092</td>
</tr>
<tr>
<td>Travel on State Road System, $10^6$ veh. mi.</td>
<td>24,480</td>
<td>29,797</td>
<td>27,619</td>
<td>28,483</td>
<td>29,755</td>
<td>28,376</td>
</tr>
<tr>
<td>Crash Rates for State Road System,</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crashes/$10^8$ vehicle mile</td>
<td>287.3</td>
<td>273.1</td>
<td>324.4</td>
<td>261.7</td>
<td>257.3</td>
<td>289.3</td>
</tr>
</tbody>
</table>
### Number of Crashes in Georgia by Type of Crash, Time of Day and Year

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Run off road</td>
<td>Day</td>
<td>12,656</td>
<td>13,939</td>
<td>14,073</td>
<td>14,779</td>
<td>13,941</td>
</tr>
<tr>
<td></td>
<td>Night</td>
<td>9,410</td>
<td>10,446</td>
<td>10,474</td>
<td>11,715</td>
<td>11,961</td>
</tr>
<tr>
<td>Other</td>
<td>Day</td>
<td>110,016</td>
<td>118,073</td>
<td>123,448</td>
<td>121,152</td>
<td>109,747</td>
</tr>
<tr>
<td></td>
<td>Night</td>
<td>21,765</td>
<td>22,854</td>
<td>24,156</td>
<td>25,152</td>
<td>23,545</td>
</tr>
</tbody>
</table>

**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).
REDUCTION IN NIGHT CRASHES DUE TO REFLECTORIZED MARKERS
PUT IN PLACE DURING 1976–1978 IN GEORGIA
CUMULATIVE NUMBER OF NIGHT CRASHES AT STUDY SITES

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