Investigating Safety Impact of Raised Pavement Markers on Freeways in Louisiana

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ABSTRACT

Raised pavement markers (RPM) are intended as safety devices on roadways. Intuitively convinced by its safety benefits Louisiana Department of Transportation and Development (LADOTD) has been using RPM for many years on all freeways in the state. Because of the not-so-positive RPM Crash Modification Factor published by the first Highway Safety Manual the state has to evaluate safety benefits of PRM in a warm climate. A study was conducted by Louisiana Transportation Research Center to investigate RPM safety impact on freeway crashes with nine years of data. The safety effect of freeway striping was also evaluated since the condition rating on RPM and striping are made concurrently every year. The analysis results from three methods indicate that RPM has significant effect in reducing crashes particularly nighttime crashes at all AADT levels. For AADT under 20,000, probability of getting positive safety effect is given by the HSM as 0.26 with 1.13 CMF and a standard error of 0.2. For the same AADT, the probability of positive safety effect is estimated by this study as 0.97 on rural freeways. The analysis results also indicate that RPM does not have any safety benefits on urban freeways.

Key words: roadway safety, crash risk, raised pavement markers (RPM), striping
INTRODUCTION

A raised pavement marker (RPM) is intended as a safety device installed on roadways. These devices are usually made with plastic, ceramic, or occasionally metal, and come in a variety of shapes and colors. Many varieties include a lens or sheeting that enhances their visibility by reflecting automotive headlights.

Intuitively convinced by its safety benefits Louisiana Department of Transportation and Development (LADOTD) has been using RPM for many years on all freeways in the state. As with many highway devices, RPM needs to be replaced periodically to maintain its intended functionality, which requires significant resource. To select the most efficient crash countermeasure under the limited resource, the effects of all crash countermeasures need to be understood and qualitatively measured.

Although the safety benefit of RPM is intuitively felt by drivers in Louisiana, there are not many qualitative studies conducted showing its capability in crash reduction. The crash modification factor (CMF) for RPM listed in the first edition of the Highway Safety Manual (HSM) has the CMF bigger than one for AADT less than 20,000.

There is a need to substantiate the effect of RPM in order to decide the continuation of RPM on freeways in Louisiana, which is precisely the purpose of this study.

LITERATURE REVIEW

Due to its popularity, numerous studies were conducted on the evaluation of RPM. But majority of these researchers were concerned with RPM installation procedure, durability, retro-reflectivity, costs, and optimum spacing. Relatively few studies have been conducted during the last 30 years on the safety effectiveness of RPM.

Wright et al. (1) evaluated the safety effectiveness of reflective raised pavement markers in 1982. From 1976 to 1978, the Georgia Department of Transportation installed reflective pavement markers on the centerlines of 662 horizontal curves. The study focused to predict the change in nighttime crashes. Daytime crashes were also used at the same sites for comparison purpose. The results from the study showed 22 percent reduction of nighttime crashes with comparison to daytime crashes at the same sites.

A before-and-after study was conducted by Kugle et al. (2) in 1984. Two years of before-and-after crash data from 469 Texas sites (varying in length from 0.2 to 24.5 miles) were used for analysis. About 65 percent study sites were on two-lane roads, the rest are mostly on four-lane roadways. Three different evaluation methods were used in this study. The result showed the increment of nighttime crashes by 15 to 30 percent after RPM installation. Mak et al. (3) performed a study on the same dataset of Kugle et al. to re-examine the impact of RPM on the nighttime crashes. In this study, the locations of the previous study were reinvestigated to specify the safety effect of RPM rather than the influence of other countermeasures. A logit model was developed to inspect the statistical significance by means of daytime crashes as the comparison group, which generated mixed results – the 4.6 percent sites showed significant decrease in nighttime crashes, 10.3 percent sites showed significant crash increase, the rest 85.1 percent showed non-significant effects.

Griffin (4) analyzed the re-screened data from the Mak et al study by deploying a different statistical approach. Using yoked comparison before and after methodology, the expected change in nighttime crashes following the installation of RPM was estimated to be a 16.8 percent increase, with the 95 percent confidence limits between a 6.4 and 28.3 percent increase.
increase. No information regarding the setting (urban or rural) of these roadways was mentioned under the study.

Pendleton (5) used both traditional and empirical Bayes before-and-after methods to assess the safety impact of RPM on the nighttime crashes on both divided and undivided arterials in Michigan. Seventeen locations (length=56 miles) were considered as treatment sites, and 42 sites (length= 146 miles) were used as control sites with no RPM. Crash data for 2 years prior and 2 years after RPM placement were considered for the analysis. Undivided roadways showed an increase in nighttime crashes and divided roadways showed a decrease in nighttime crashes. The empirical Bayes methodology produced smaller drop than the conventional before-and-after methodology.

New York State Department of Transportation (DOT) (6) performed a simple before-and-after safety investigation of RPM in New York. In this study number of crashes prior and after the RPM placement was compared without controlling for other factors. On unlit suburban and rural roadways there was a non-significant 7 percent decrease in total crashes and a significant 26 percent decrease in nighttime crashes. On highway sections with proper lightings, the nighttime crashes were reduced by 8.6 percent and the total crashes were reduced by 7.4 percent.

Orth-Rodgers and Associates, Inc. (7), used the same methodology as Griffin to assess the effects of raised pavement markers on nighttime crashes at 91 Interstate highway locations in Pennsylvania. The results showed a significant crash increase – 18 percent increase at nighttime crashes, 30 to 47 percent crash increase at nighttime under wet pavement conditions.

The above discussed studies have conflicting conclusions on the RPM impact, which called for a comprehensive study by the National Cooperative Highway Research Program (NCHRP) in 2004 to evaluate the safety effects of raised pavement markers (8). The data from two-lane and four-lane highways were collected from the six states for the analysis. The NCHRP study developed the Crash Modification Factors (CMF) for rural four-lane freeways that is published in the first edition of HSM (9) as shown in TABLE 1.

**TABLE 1 Potential Crash Effects of Installing Snowplowable Permanent Raised Pavement Markers from the HSM (Exhibit 13-51)**

<table>
<thead>
<tr>
<th>Setting (Road Type)</th>
<th>Traffic Volume (AADT)</th>
<th>Crash Type (Severity)</th>
<th>CMF</th>
<th>Std. Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rural (Four-lane Freeways)</td>
<td>≤ 20,000</td>
<td>Nightime</td>
<td>1.13</td>
<td>0.2</td>
</tr>
<tr>
<td>Rural (Four-lane Freeways)</td>
<td>20,001-60,000</td>
<td>All Types</td>
<td>0.94</td>
<td>0.3</td>
</tr>
<tr>
<td>Rural (Four-lane Freeways)</td>
<td>&gt;60,000</td>
<td>(All Sevities)</td>
<td>0.67</td>
<td>0.3</td>
</tr>
</tbody>
</table>

In summary, the previous studies on the safety effectiveness of RPM had either limited number of samples or do not separate rural from urban roadways in their analyses, which may explain some of their conflicting results. The NCHRP project did have large sample size but the results show a negative impact of RPM on roadway safety when AADT is less than or equal to 20,000. There are 40 percent of rural freeways in Louisiana with AADT less than or equal to 20,000. (97.2 percent of Louisiana rural freeways are four-lane highways). None of the rural freeway segments in Louisiana before year 2010 has AADT higher than 60,000.
INITIAL DATA ANALYSIS

The quality of RPM along with pavement striping (center and edge lines) on Louisiana freeways is inspected annually by one designated engineer who gives subjective ratings. Three categories of rating (good, fair and poor) are used to describe the condition of RPM and striping. The segments in poor condition will be scheduled for either RPM replacement or re-striping. The nine years (2002-2010) of RPM and striping ratings for all Louisiana freeways were obtained for the analysis along with the corresponding nine years of crash data. On the average, the good rating for RPM lasts 2.2 years and for striping 3.28 years. During the nine years, a segment would experiences several cycles (from good to poor) of ratings for RPM or striping.

The PRM and striping ratings are made independently based on the control section, a segmentation method used by LaDOTD. Totally there are close to 900 miles of freeways in 533 segments. Within each defined segment, the roadway major attributes, such as lane width, shoulder width, number of lanes, type of pavement, AADT and etc, remain the same. The nine year crashes were populated to each segment based on their longitudinal and latitudinal codlings.

Because of the difference in segment length and AADT, crash frequency can not be directly used for comparison. Thus, crash rate (crashes per 100 million VMT) is calculated for each segment. Due to the difference in freeway design and operation, the analysis is conducted for rural and urban separately.

There are nine possible annual rating combinations, such as GG, GF, GP, FG, FF, FP, PG, PF and PP with the first letter for RPM and the second for striping (G as good, F as fair and P as poor). Sample crash years of data for the used categories are shown in TABLE 2 and the summary of ratings is listed in TABLE 3.

<table>
<thead>
<tr>
<th>Control Section</th>
<th>Length</th>
<th>Rating</th>
<th>Crashes/mile</th>
<th>Rating</th>
<th>Crashes/mile</th>
<th>Rating</th>
<th>Crashes/mile</th>
<th>Rating</th>
<th>Crashes/mile</th>
<th>Rating</th>
<th>Crashes/mile</th>
<th>Rating</th>
<th>Crashes/mile</th>
<th>Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>450-91</td>
<td>1.36</td>
<td>GP</td>
<td>1</td>
<td>GG</td>
<td>10</td>
<td>GF</td>
<td>4</td>
<td>PF</td>
<td>3</td>
<td>FP</td>
<td>11</td>
<td>FP</td>
<td>4</td>
<td>PG</td>
</tr>
<tr>
<td>450-91</td>
<td>3.4</td>
<td>GP</td>
<td>2</td>
<td>GG</td>
<td>4</td>
<td>GF</td>
<td>4</td>
<td>PF</td>
<td>2</td>
<td>FP</td>
<td>1</td>
<td>FP</td>
<td>1</td>
<td>PG</td>
</tr>
<tr>
<td>450-91</td>
<td>1.17</td>
<td>GP</td>
<td>3</td>
<td>GG</td>
<td>2</td>
<td>GF</td>
<td>3</td>
<td>FP</td>
<td>0</td>
<td>FP</td>
<td>1</td>
<td>FP</td>
<td>1</td>
<td>PG</td>
</tr>
<tr>
<td>450-91</td>
<td>0.13</td>
<td>GP</td>
<td>0</td>
<td>GG</td>
<td>0</td>
<td>GF</td>
<td>0</td>
<td>FP</td>
<td>0</td>
<td>FP</td>
<td>8</td>
<td>FP</td>
<td>0</td>
<td>PG</td>
</tr>
<tr>
<td>450-91</td>
<td>0.38</td>
<td>GP</td>
<td>3</td>
<td>GG</td>
<td>3</td>
<td>GF</td>
<td>0</td>
<td>FP</td>
<td>0</td>
<td>FP</td>
<td>3</td>
<td>FP</td>
<td>3</td>
<td>PG</td>
</tr>
<tr>
<td>450-91</td>
<td>0.58</td>
<td>FF</td>
<td>16</td>
<td>PC</td>
<td>0</td>
<td>CC</td>
<td>0</td>
<td>FP</td>
<td>0</td>
<td>FP</td>
<td>0</td>
<td>GP</td>
<td>0</td>
<td>GG</td>
</tr>
<tr>
<td>450-91</td>
<td>0.21</td>
<td>FF</td>
<td>0</td>
<td>GG</td>
<td>24</td>
<td>CC</td>
<td>5</td>
<td>FP</td>
<td>0</td>
<td>FP</td>
<td>0</td>
<td>GP</td>
<td>0</td>
<td>GG</td>
</tr>
<tr>
<td>450-91</td>
<td>0.18</td>
<td>FF</td>
<td>28</td>
<td>GG</td>
<td>6</td>
<td>GG</td>
<td>6</td>
<td>FP</td>
<td>0</td>
<td>FP</td>
<td>11</td>
<td>GP</td>
<td>0</td>
<td>GG</td>
</tr>
<tr>
<td>450-91</td>
<td>0.44</td>
<td>FF</td>
<td>20</td>
<td>GG</td>
<td>9</td>
<td>GG</td>
<td>5</td>
<td>FP</td>
<td>2</td>
<td>FP</td>
<td>7</td>
<td>GP</td>
<td>2</td>
<td>GG</td>
</tr>
<tr>
<td>450-91</td>
<td>2.43</td>
<td>PP</td>
<td>14</td>
<td>FP</td>
<td>9</td>
<td>PP</td>
<td>11</td>
<td>PP</td>
<td>5</td>
<td>GG</td>
<td>12</td>
<td>FP</td>
<td>5</td>
<td>GG</td>
</tr>
<tr>
<td>450-91</td>
<td>0.22</td>
<td>PP</td>
<td>0</td>
<td>FP</td>
<td>0</td>
<td>PP</td>
<td>0</td>
<td>PP</td>
<td>0</td>
<td>GG</td>
<td>0</td>
<td>GP</td>
<td>0</td>
<td>GG</td>
</tr>
<tr>
<td>450-91</td>
<td>0.08</td>
<td>PP</td>
<td>0</td>
<td>FP</td>
<td>0</td>
<td>PP</td>
<td>0</td>
<td>PP</td>
<td>0</td>
<td>GG</td>
<td>0</td>
<td>GP</td>
<td>0</td>
<td>GG</td>
</tr>
<tr>
<td>450-91</td>
<td>1.2</td>
<td>PP</td>
<td>3</td>
<td>FP</td>
<td>4</td>
<td>PP</td>
<td>3</td>
<td>PP</td>
<td>3</td>
<td>GG</td>
<td>6</td>
<td>GG</td>
<td>5</td>
<td>GG</td>
</tr>
<tr>
<td>450-91</td>
<td>0.14</td>
<td>PP</td>
<td>7</td>
<td>FP</td>
<td>14</td>
<td>PP</td>
<td>7</td>
<td>PP</td>
<td>7</td>
<td>GG</td>
<td>7</td>
<td>GG</td>
<td>0</td>
<td>GG</td>
</tr>
<tr>
<td>450-91</td>
<td>0.31</td>
<td>PP</td>
<td>0</td>
<td>FP</td>
<td>3</td>
<td>PP</td>
<td>0</td>
<td>PP</td>
<td>0</td>
<td>GG</td>
<td>3</td>
<td>GG</td>
<td>0</td>
<td>GG</td>
</tr>
</tbody>
</table>
TABLE 3 Summaries of Freeway Segments in Different Ratings

<table>
<thead>
<tr>
<th>Freeway Location</th>
<th>Number of Segments in Each Rating Group</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>GG</td>
</tr>
<tr>
<td>Rural</td>
<td>606</td>
</tr>
<tr>
<td>Urban</td>
<td>1,028</td>
</tr>
<tr>
<td>Total</td>
<td>1,634</td>
</tr>
</tbody>
</table>

Note: segments under major maintenance/reconstruction marked as C are not counted.

Excluding the mixed ratings from RPM and striping, the first focus of the analysis was only on the cases with both ratings in the same category. FIGURE 1 compares the crash rate for the rural freeway segment, where the overall average crash rate for both RPM and striping with quality rating $k$, $R_k$ is computed as:

$$
R_k = \frac{\sum_{i} \bar{r}_{k,i}}{N}
$$

Where, $bar{r}_{k,i}$ = average crash rate over nine years on segment $j$ with both rating as $k$

$r_{k,i,j}$ = crash rate of segment $j$ at year $i$ with both ratings as $k$

$N$ = number of segments

$M_k$ = number of years both ratings in $k$ for segment $j$

FIGURE 1 Average crash rate by different ratings on rural freeway

It is encouraging to see that the quality of RPM and striping does make a difference in the crash rate. As the combined ratings go from good to poor, the overall average crash rate increases. Since the RPM is particularly important at night for outlining traveled lanes, the nighttime crash rate is also computed with the 24-hour AADT, which shows the same trend. The increasing crash rate from good rating to poor rating is 22 percent for 24-hour crash rate.
calculation, and 23 percent for nighttime crash rate estimation. However, as shown in FIGURE 2, the overall average crash rates do not reveal any positive effect of RPM and striping on the urban freeways, which is similar to the CMF listed in the first edition of HSM.

![FIGURE 2 Average crash rates by different ratings on urban freeway](image)

It is a challenge to estimate the safety effect of RPM and striping separately since both have somewhat similar functionalities. FIGURE 3 illustrates how overall average crash rates on rural freeways vary by either RPM or striping ratings at both 24 and night hours.

![FIGURE 3 Average crash rates by single rating (RPM or striping)](image)
The positive safety effect is still evident even with only one single rating as shown in Figure 3 where the lowest crash rate is always associated with a good rating on either RPM or striping. It is recognized that with one feature (RPM or striping) at rating k, the rating for the other feature can be in all three categories. That is, while a RPM in good rating, the rating for striping can be good, fair and poor at the same time and location, which explains why the difference in the average crash rate between rating good and poor for a single feature is not as big as the difference in the combined ratings between GG and PP. But nevertheless, the initial data analysis does demonstrate the safety effect of RPM and striping independently.

### STATISTICAL TESTING

The initial analysis results show the difference in crash rate between good and poor ratings for RP and striping. Whether or not these differences are significant in the statistical terms were then examined, in which the rating from each year on all rural freeway segments are used in the statistical test as one independent data sample instead of the segment averages. The difference of crash rate under good and poor ratings is examined by the t-test for Equality of Means, which are listed in TABLE 4.

<table>
<thead>
<tr>
<th>AADT ≤ 60,000</th>
<th>Feature</th>
<th>Crash Rate at</th>
<th>t-test for Equality of Means</th>
<th>Feature Rating at</th>
<th>Crash Rate at</th>
<th>t-test for Equality of Means</th>
<th>Feature Rating at</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>t</td>
<td>df</td>
<td>Significance (2-tailed)</td>
<td>Mean Difference</td>
<td>Std. Error Difference</td>
</tr>
<tr>
<td>Rural RPM Night</td>
<td>-2.128</td>
<td>1339</td>
<td>0.033</td>
<td>-0.025</td>
<td>0.012</td>
<td>-0.049</td>
<td>-0.002</td>
</tr>
<tr>
<td>Rural RPM 24 hour</td>
<td>-2.573</td>
<td>1339</td>
<td>0.010</td>
<td>-0.045</td>
<td>0.016</td>
<td>-0.077</td>
<td>-0.013</td>
</tr>
<tr>
<td>Rural RPM+Striping Night</td>
<td>-2.800</td>
<td>889</td>
<td>0.005</td>
<td>-0.186</td>
<td>0.053</td>
<td>-0.289</td>
<td>-0.082</td>
</tr>
<tr>
<td>Rural RPM+Striping 24 hour</td>
<td>-3.504</td>
<td>889</td>
<td>0.000</td>
<td>-0.212</td>
<td>0.082</td>
<td>-0.373</td>
<td>-0.051</td>
</tr>
</tbody>
</table>

### Table 4 Results of Statistical Tests

The statistic testing results shows the safety effect of RPM slightly varies by AADT. The crash rate difference between two ratings is, indeed, statistically significant for RPM alone and RPM plus striping for AADT bigger than 20,000 as shown in the bottom of TABLE 3. The negative lower and upper bound of the estimated mean difference at 95 percent confident level ascertains the positive effect of RPM and striping, jointly and separately for the rural freeways with AADT bigger than 20,000. Although the similar results are also seen on the upper part of the table showing the results for all rural freeways, the testing results on the middle part of the table are slightly different. For the rural freeway segments with AADT less than 20,000, the crash rate difference between two RPM ratings is only statistically significant at nighttime (at 90 percent confidence level). The positive upper bound of 0.003 indicates the existence of uncertainty. The results from this study are somewhat different from the CMF given by the HSM. Since crash rate (used in our study) and CMF are two different concepts, we cannot simply
compare their values. However, the RPM effect expressed by the CMF and crash rate difference can be illustrated by the probability calculation based on the information listed in TABLE 1 and from this study. For AADT under 20,000, probability of getting positive safety effect is calculated as 0.26 with 1.13 CMF and a standard error of 0.2. For the same AADT, the probability of positive safety effect is calculated as 0.97 with the crash rate difference of -0.033 and a standard error of 0.018. Both calculations are displayed in FIGURE 4.

![Probability distribution](image.png)

**FIGURE 4 Probability of positive safety effect of RPM from the CMF and crash rate**

For AADT between 20,000 and 60,000, the probability of getting positive RPM effect is one from this study and is .58 from the HSM.

As expected, the test on the urban freeways shows no significant difference (either positive or negative) in crash rate under all scenarios.

**WITH AND WITHOUT ANALYSIS**

Although the analysis with crash rate was considered the most reliable method for the evaluation, another method was also used to explore the safety effects of RMP and Striping at nighttime. Lacking a Safety Predictive Model for freeway, the direct application of many safety evaluation methods recommended by the HSM is not suitable for this unique case. A so-called “with and without” crash analysis was performed, which not only considers AADT changes but also accommodates the difference in segment length.

The analysis method divides the ratings of each segment in nine years into two groups as “with” (with good rating) and “without” (with poor rating). Two adjustment factors, $r_a(j)$ and $r_s(j)$, are developed to account for AADT changes during the analysis years and different sample size between “with” and “without” groups.

\[
  r_a(j) = \frac{\overline{A}_{wj}}{\overline{A}_{WTj}} \tag{2}
\]

\[
  r_s(j) = \frac{N_{wj}}{N_{WTj}} \tag{3}
\]

Where
\( \bar{A}_{wj} = \text{average AADT of “with” group for segment } j \)

\( \bar{A}_{wTj} = \text{average AADT of “without” group for segment } j \)

\( N_{wj} = \text{number of years under “with” group for segment } j \)

\( N_{wTj} = \text{number of years under “without” group for segment } j \)

The analysis results are given in TABLE 5, which show a clear crash reduction at night for RPM.

TABLE 5 “With” and Without” Crash Analysis for Rural Freeways at Nighttime

<table>
<thead>
<tr>
<th>Feature Type</th>
<th>Number of Sections</th>
<th>With (Good)</th>
<th>Without (Poor)</th>
<th>Expected Crash Reduction</th>
<th>% Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>RPM</td>
<td>114</td>
<td>641</td>
<td>675</td>
<td>34</td>
<td>5.30%</td>
</tr>
<tr>
<td>Striping</td>
<td>77</td>
<td>476</td>
<td>477</td>
<td>1</td>
<td>0.20%</td>
</tr>
</tbody>
</table>

DISCUSSION AND CONCLUSION

Among the three analyses that all show the positive impact of RPM on rural freeway safety in Louisiana, it is believed that the results from the statistical test offer the most reliable information. The other two analyses are based on the segment average over the nine years for either AADT or crashes, which not only greatly reduces the number of samples but also loses the accuracy of the results.

It is possible that other crash countermeasures were implemented on the rural freeways during these nine analysis years. Since the RPM condition cycle is short (average 2.2 years in good rating) and annual RPM ratings are different at different locations, the effect of other crash countermeasures would not significantly affect the results. Based on the analysis, workzone presents the biggest impact on freeway safety. The highest crash rates are consistently associated with the freeway segment under construction. When a freeway segment was under construction or major maintenance, the RPM and striping rating was coded as C, thus excluded from the analysis.

Although the rating on RPM and striping are subjective, it is believed that the errors caused by the subjective evaluation from one single designated engineer could be consistent over space and in time. The effect of subjective rating on the analysis results should be minimal if not totally ignorable when the analysis is focused on the difference between good and poor conditions. Concerning potential errors in the subjective rating, the RPM under fair conditions was not included in the analysis.

In summary, this study indicates clearly that RPM does make a difference on rural freeway safety under all AADT conditions in Louisiana. The RPM should be continually maintained on rural freeways in the state. The study also confirms that there are no safety benefits for RPM on urban freeways probably due to lighting conditions. For well-lit urban freeways, there is no need to implement RPM.
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