Investigating the 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 their safety benefits, the Louisiana Department of Transportation and Development (LADOTD) has been using RPMs for many years on all freeways in the state. Because of the not-so-positive RPM Crash Modification Factor published in the first Highway Safety Manual, the state has to evaluate safety benefits of RPMs in a warm climate. A study was conducted by the 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 RPMs and striping are made concurrently every year. The analysis results from the three methods indicated that RPMs have a significant effect in reducing crashes, particularly nighttime crashes at all AADT levels. For Annual Average Daily Traffic (AADT) under 20,000, the probability of getting a positive safety effect is given by the Highway Safety Manual (HSM) as 0.26 with a 1.13 Crash Modification Factor (CMF) and a standard error of 0.2. For the same AADT, the probability of a positive safety effect was estimated by this study as 0.97 on rural freeways. The analysis results also indicated that RPMs do not have any safety benefits on urban freeways.

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, the Louisiana Department of Transportation and Development (LADOTD) has been using RPMs for many years on all freeways in the state. As with many highway devices, RPMs need to be replaced periodically to maintain their intended functionality, which requires significant resources. To select the most efficient crash countermeasure with the limited resources, the effects of all crash countermeasures need to be understood and qualitatively measured. Although the safety benefits of the RPMs are intuitively felt by drivers in Louisiana, there have not been many qualitative studies conducted showing their capabilities in crash reduction. The crash modification factor for the RPMs listed in the first edition of the Highway Safety Manual (HSM) has a CMF greater than one for AADT less than 20,000.

There is a need to substantiate the efficacy of RPMs in order to decide whether or not to continue the use of RPMs on freeways in Louisiana, which was precisely the purpose of this study.

Literature Review

Due to their popularity, numerous studies have been conducted on the evaluation of RPMs. The majority of these studies, however, were concerned with RPM installation procedures, durability, retro-reflectivity, costs, and optimum spacing. Relatively few studies have been conducted during the last 30 years on the safety effectiveness of RPMs. Wright et al. [1] evaluated the safety effectiveness of reflective raised pavement markers. From 1976 to 1978, the Georgia Department of Transportation installed reflective pavement markers on the centerlines of 662 horizontal curves. The study was intended to predict the change in nighttime crashes. Daytime crashes were also used at the same sites for comparative purposes. The results from the study showed a 22-percent reduction of nighttime crashes, compared with daytime crashes at the same sites.

A before-and-after study was conducted by Kugle et al. [2]. 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 of the study sites were on two-lane roads; the rest were mostly on four-lane roadways. Three different evaluation methods were used in this study. The results 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 [2] in order to re-examine the impact of RPMs on nighttime crashes. In this current study, the RPM locations used in the previous study were reinvestigated to analyze the safety effect of RPMs rather than the influence of other countermeasures. A logit model was developed to evaluate the statistical significance by means of daytime crashes as the comparison group, which generated mixed results: 4.6 percent of the sites showed a significant decrease in nighttime crashes; 10.3 percent of the sites showed a significant crash increase; the rest, 85.1 percent, showed non-significant effects.

Griffin [4] analyzed the re-screened data from the Mak et al. [3] study by deploying a different statistical approach. Using a yoked comparison before-and-after methodology, the expected change in nighttime crashes following the installation of RPMs was estimated to be a 16.8 percent increase at the 95 percent confidence limits between a 6.4 and 28.3 percent increase. No information regarding the setting (urban or rural) of these roadways was mentioned in the study. Pendleton [5] used both traditional and empirical Bayes before-and-after methods to assess the safety impact of RPMs 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 (approximate length = 146 miles) were used as control sites with no RPMs. Crash data for two years prior and two years after RPM placement were considered for the analysis. Undivided roadways showed a rise in nighttime crashes and divided roadways showed a decrease in nighttime crashes. The empirical Bayes methodology produced a smaller drop than the conventional before-and-after methodology. The New York State Department of Transportation (DOT) performed a simple before-and-after safety investigation of RPMs in New York [6].

In this study, the number of crashes before and after the placement of the RPMs 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 lighting, nighttime crashes were reduced by 8.6 percent and total crashes were reduced by 7.4 percent. Orth-Rodgers and Associates, Inc. [7], used the same methodology as Griffin [4] to assess the effects of RPMs on nighttime crashes at 91 Interstate highway locations in Pennsylvania. The results showed a significant crash increase of 18 percent for nighttime crashes and 30 to 47 percent for nighttime under wet pavement conditions.

The aforementioned studies have conflicting conclusions on the impact of RPMs, which called for a comprehensive study by the National Cooperative Highway Research Program (NCHRP) in 2004 [8] to evaluate the safety effects of raised pavement markers. 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 was published in the first edition of HSM, as shown in Table 1 [9].

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

Setting (Road Type)	Traffic Vol. (AADT)	Crash Type (Severity)	CMF	Std. Error
Rural (Four-lane Freeways)	≤ 20,000	Nighttime All Types (All severities)	1.13	0.2
	20,001-60,000		0.94	0.3
	> 60,000		0.67	0.3

In summary, the previous studies on the safety effectiveness of RPMs had either a limited number of samples or did not separate rural from urban roadways in their analyses, which may explain some of their conflicting results. The NCHRP project did have a large sample size, but the results showed a negative impact of RPMs on roadway safety when AADT was less than or equal to 20,000. And, in Louisiana, 40 percent of rural freeways have 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 2010 had AADT higher than 60,000.

Initial Data Analysis

The quality of RPMs 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 ratings (good, fair, and poor) are used to describe the condition of the RPMs 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 average, the good rating for RPMs lasts 2.2 years and 3.28 years for striping. During the nine years, a segment would experience several cycles (from good to poor) of ratings for RPMs or striping.

The RPM and striping ratings are made independently based on the control section, a segmentation method used by LADOTD. In total, there are close to 900 miles of freeways in 533 segments. Within each defined segment, the roadways' major attributes, such as lane width, shoulder width, number of lanes, type of pavement, AADT, etc., remain the same. The nine years' worth of crashes were populated into each segment based on their longitudinal and latitudinal codlings. Because of the difference in segment length and AADT, crash frequency could not be directly used for comparison. Thus, the crash rate (crashes per 100 million Vehicle Mileage Traveled [VMT]) was calculated for each segment. Due to the difference in freeway design and operation, the analysis was conducted for rural and urban highways separately. There are nine possible annual rating combinations—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 3. Summaries of Freeway Segments in Different Ratings

Freeway Location	Number of Segments in Each Rating Group								
	GG	GF	GP	FG	FF	FP	PG	PF	PP
Rural	606	85	171	63	110	140	75	31	285
Urban	1,028	189	280	156	214	266	141	88	734
Total	1,634	274	451	219	324	406	216	119	1,019

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

Excluding the mixed ratings from RPMs and striping, the first focus of the analysis was only on the cases with both ratings in the same category. Figure 1 shows a comparison of the crash rates for the rural freeway segment, where the overall average crash rate for both RPMs and striping with quality rating k is computed as:

$$\overline{R}_k = \frac{\sum_i \overline{r}_{k\,i}}{N} \qquad \overline{r}_{k\,i} = \frac{\sum_j r_{k\,i\,j}}{M_k} \qquad (1)$$

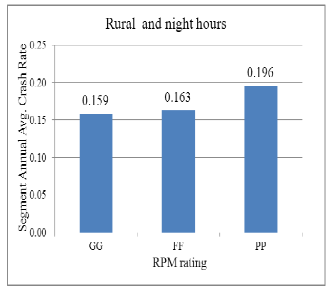
where,

$\overline{r}_{ki}$ = average crash rate over nine years on segment j with both ratings as k

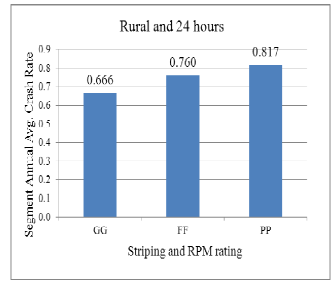
$r_{k\,i\,j}$ = crash rate of segment j at year i with both ratings as k

N = number of segments

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



(a) Rural and Night Hours



(b) Rural and 24 Hours

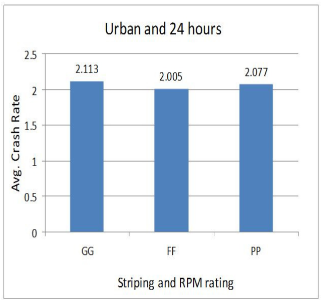
Figure 1. Average Crash Rates on Rural Freeways

It is encouraging to see that the quality of RPMs 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 was 22 percent for the 24-hour crash rate calculation, and 23 percent for nighttime crash rate estimation. However, as shown in Figure 2, the overall average crash

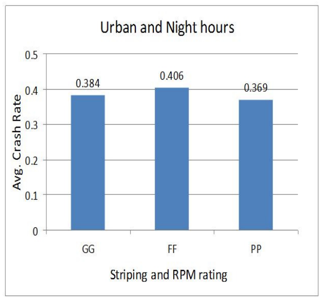
Table 2. Sample Crash Years of Data for the Used Categories

		2004		2005		2006		2007		2008		2009		2010	
Control Section	Length	Rating	Crash-es/ Mile	Rating	Crashes/ Mile	Rating	Crashes/ Mile	Rating	Crashes/ Mile	Rating	Crashes/ Mile	Rating	Crashes/ Mile	Rating	Crashes/ Mile
450-91	1.36	GP	1	GG	2	GF	1	FP	1	FP	3	FP	2	PG	1
450-91	3.4	GP	2	GG	3	GF	2	FP	2	FP	2	FP	1	PG	1
450-91	1.17	GP	0	GG	1	GF	1	FP	0	FP	0	FP	0	PG	0
450-91	0.13	GP	0	GG	0	GF	0	FP	0	FP	0	FP	0	PG	0
450-91	0.38	GP	0	GG	0	GF	0	FP	0	FP	0	FP	0	PG	0
450-91	0.58	FF	4	PC	1	CC	1	FP	1	FP	0	GP	1	GG	0
450-91	1.04	PP	2	PP	2	PP	2	PP	3	CC	1	GG	1	GG	1
450-03	0.76	GF	1	GP	1	GG	1	GF	1	FP	1	GG	1	GG	1
450-03	3.35	GF	2	GP	2	GG	3	GF	3	FP	1	FP	2	PG	2
450-03	5.62	GF	2	GP	4	GG	3	GF	3	FP	2	FP	2	PG	2
450-03	0.73	GF	0	GP	0	GG	1	GF	0	FP	0	FP	0	PG	0
450-03	1.79	GG	1	GP	1	GG	1	FP	0	FP	0	FP	0	PG	0
450-03	3.01	GG	1	GP	1	GG	2	FP	1	FP	1	FP	2	PG	1
450-03	4.7	GG	3	GP	4	GG	5	FP	4	FP	2	FP	3	PG	3
450-06	0.38	PP	0	PP	1	PP	0	GG	0	GF	0	GP	0	PG	0

rates do not reveal any positive effect of RPMs and striping. It is a challenge to estimate the safety effect of RPMs 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 over both nighttime and 24-hour periods.



(a) Urban and 24 Hour



(b) Urban and Night Hours

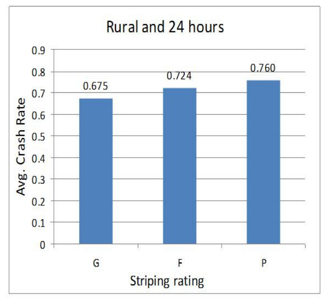
Figure 2. Average Crash Rates on Urban Freeways

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 RPMs or striping. It can be seen that with one feature (RPM or striping) at rating k, the rating for the other feature can be in all three categories. That is, a RPM can have a good rating, while the rating for striping can be good, fair, or poor at the same time and location, which explains why the difference in the average crash rates between good ratings and poor for a single feature is not as big as the difference in the combined ratings between GG and PP. Nevertheless, the initial data analysis did demonstrate the safety effect of RPMs and striping independently.

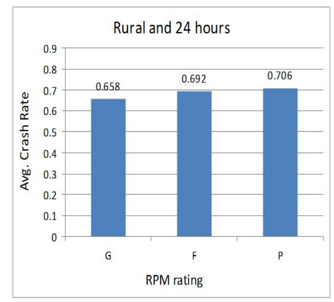
Statistical Testing

The initial analysis results showed the difference in crash rates between good and poor ratings for RP and striping. Whether or not these differences were significant in statistical terms was then examined, where the ratings from each year on all rural freeway segments were used in the statistical test as one independent data sample instead of the segment averages. The differences between crash rates for good and poor ratings were examined by using a t-test at three AADT levels. The results of the statistical testing are listed in Table 4.

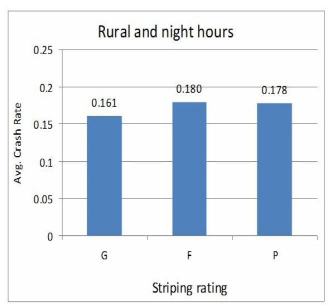
The statistic testing results show the safety effect of RPMs varies slightly by AADT. The crash rate difference between the two ratings was, indeed, statistically significant for RPMs alone and RPMs plus striping for AADT bigger than 20,000, as shown at the bottom of Table 3. The negative lower and upper bounds of the estimated mean difference at the 95-percent confident level ascertains the positive effect of RPMs and striping, jointly and separately, for rural freeways with AADT bigger than 20,000. Although similar results can also be seen in the upper part of the table showing the results for all rural freeways, the test results in 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 was only statistically significant for nighttime data (at the 90-percent confidence level). The positive upper bound of 0.003 indicates the existence of uncertainty.



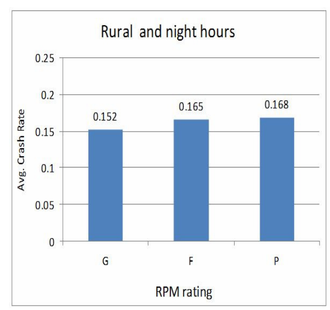
(a) Striping for Rural and 24 Hours



(b) RPMs for Rural and 24 Hours



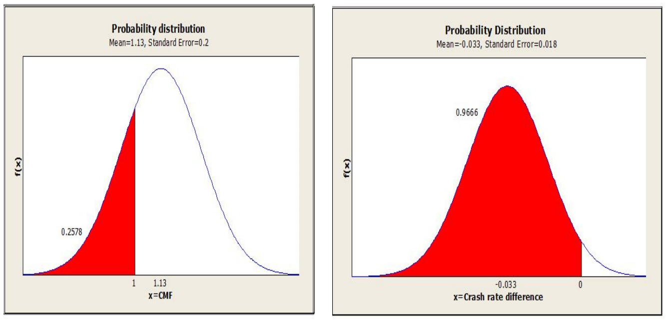
(c) Striping Ratings for Rural and Night Hours



(d) RPM Ratings for Rural and Night Hours

Figure 3. Average Crash Rates by Single Rating

The results from this study were somewhat different from the CMF given by the HSM. Since crash rate (used in this current study) and CMF are two different concepts, one 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, the probability of getting a positive safety effect was calculated as 0.26 with 1.13 CMF and a standard error of 0.2. For the same AADT, the probability of a positive safety effect was 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.



(a) CMF **(b) Crash Rates**

Figure 4. Probability of Positive Safety Effects of RPMs

For AADT between 20,000 and 60,000, the probability of getting a positive RPM effect is 1 from this study and 0.58 from the HSM. As expected, the test on the urban freeways showed no significant difference (either positive or negative) in crash rates under all scenarios.

With and Without Analysis

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

The analysis method divided the ratings of each segment from nine years into two groups as "with" (with good rating) and "without" (with poor rating). Two adjustment factors, $r_{a(j)}$ and $r_{s(j)}$, were developed to account for AADT changes during the analysis years and different sample sizes between the "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,

$\overline{A}_{wj}$ = average AADT of "with" group for segment j

$\overline{A}_{wTj}$ = average AADT of "without" group for segment j

N_{Wj} = number of years under "with" group for segment j

N_{WTj} = 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 RPMs.

Table 5. "With" and Without" Crash Analysis for Rural Freeways at Nighttime

		Expected Crashes			
Feature Type	**Number of Sections**	**With (Good)**	**Without (Good)**	**Expected Crash Reduction**	**% Reduction**
RPM	114	641	675	34	5.30%
Stripping	77	476	477	1	0.20%

Table 4. Results of Statistical Tests

Roadway Type	Feature	Crash Rate at	t-test for Equality of Means						
			t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
								Lower	Upper
AADT ≤ 20,000									
Rural	RPM	Night	-1.781	489	0.076	-0.033	0.018	-0.069	0.003
Rural	RPM	24 Hrs	-1.101	489	0.271	-0.065	0.059	-0.181	0.051
Rural	RPM+Striping	Night	-2.603	309	0.010	-0.063	0.024	-0.110	-0.015
Rural	RPM+Striping	24 Hrs	-2.591	309	0.010	-0.212	0.082	-0.373	-0.051
20,000≤AADT ≤ 60,000									
Rural	RPM	Night	-2.665	816	0.008	-0.038	0.014	-0.066	-0.010
Rural	RPM	24 Hrs	-3.249	816	0.001	-0.142	0.044	-0.228	-0.056
Rural	RPM+Striping	Night	-2.285	492	0.023	-0.047	0.020	-0.087	-0.007
Rural	RPM+Striping	24 Hrs	-2.840	492	0.005	-0.168	0.059	-0.284	-0.052
AADT ≤ 60,000									
Rural	RPM	Night	-2.128	1339	0.033	-0.025	0.012	-0.049	-0.002
Rural	RPM	24 Hrs	-2.573	1339	0.010	-0.102	0.040	-0.180	-0.024
Rural	RPM+Striping	Night	-2.800	889	0.005	-0.045	0.016	-0.077	-0.013
Rural	RPM+Striping	24 Hrs	-3.504	889	0.000	-0.186	0.053	-0.289	-0.082

Discussion and Conclusion

Among the three analyses that all show the positive impact of RPMs on rural freeway safety in Louisiana, it was believed that the results from the statistical test offered the most reliable information. The other two analyses were based on the segment average over the nine years for either AADT or crashes; this 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, the work zone 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, and thus excluded from the analysis. Although the ratings on RPMs and striping were subjective, it was believed that the errors caused by the subjective evaluation from one designated engineer could be consistent over space and time. The effect of subjective ratings 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 RPMs under fair conditions were not included in the analysis.

In summary, this study clearly showed that RPMs do 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 confirmed that there are no safety benefits for RPMs on urban freeways, probably due to lighting conditions. For well-lit urban freeways, there is no need to implement RPMs.

Acknowledgements

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Biographies

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