Post-Mounted Delineators and Raised Pavement Markers: Their Effect on Vehicle Operations at Horizontal Curves on Two-Lane Rural Highways

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Post-mounted delineators (PMDs) and retroreflective raised pavement markers (RPMs), either individually or in combination, have been recommended in previous research as supplemental delineation treatments at horizontal curves on two-lane rural highways. However, these recommendations have been based on limited amounts of operational data or accident models that show little correlation between accident rates and the type of delineation treatment. No attention has been paid to the short-term effects of changing from one delineation treatment to another or to the long-term operational effectiveness of the treatments. To evaluate how vehicle operations changed, existing PMDs were removed and replaced with RPMs supplementing the existing painted centerline at five horizontal curves on two-lane rural highways in Texas. Vehicle operations were monitored on the outside lane of the curves first with the existing PMDs in place and then with the RPMs after 1 day (short-term), 6 to 11 weeks (intermediate-term), and 11 months (long-term). Operational measures of effectiveness that have been suggested by previous research to be correlated to accident experience were evaluated, including the speed at the midpoint of the curve, speed change from the beginning to midpoint of the curve, lateral placement at the midpoint of the curve, and number of vehicle encroachments into the opposing lane at the midpoint of the curve. Vehicle operations with the RPMs compared favorably with the existing PMDs in both short-term and intermediate-term evaluations. The long-term evaluation at one curve indicated that the RPMs, which had lost most of their reflectivity, continued to provide adequate near delineation, but that their far delineation was somewhat degraded.

Post-mounted delineators (PMDs) are commonly used as a supplement to standard pavement markings at horizontal curves on two-lane rural highways. Maintenance problems associated with PMDs have proven to be a nuisance. As a result, the Texas State Department of Highways and Public Transportation (SDHPT) has sought an alternative on-pavement delineation treatment to replace PMDs. Research was performed to evaluate one alternative to PMDs, retroreflective raised pavement markers (RPMs) supplementing the existing painted centerline.

Adequate path delineation is particularly important on horizontal curves. In a study on the accident characteristics of horizontal curves on two-lane rural highways, Glennon et al. (*1*) found that the average accident rate on horizontal curves is three times that of tangent sections, that the average rate of single-vehicle run-off-the-road accidents on horizontal curves is four times the rate on tangent sections, and that single-vehicle run-off-the-road accidents were proportionally greater than other accidents under wet, icy, or nighttime conditions. Glennon (*2*) also reported that more than two-thirds of the single-vehicle run-off-the-road accidents on curves were on the outside of the curves.

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A review of previous research on delineation treatments for horizontal curves on two-lane highways suggests that PMDs and RPMs, either individually or in combination, are effective supplements to painted centerlines. However, these findings have been based on limited amounts of operational data or accident models that show little correlation between accident rates and the type of delineation. No attention has been paid to the short-term effects of changing from one delineation treatment to another or to the long-term operational effectiveness of the treatments.

Therefore, a study was undertaken to evaluate the operational effectiveness of removing existing PMDs at horizontal curves on two-lane rural highways and replacing them with RPMs supplementing the existing painted centerline. The RPM treatment consisted of placing RPMs between the centerline markings at 40-ft intervals within the curve and placing four RPMs at 80-ft intervals on the tangents approaching both ends of the curve.

LITERATURE REVIEW

Two approaches have been used to evaluate the safety and operational effectiveness of PMDs and RPMs on two-lane rural highways. Some studies looked directly at the accident experience on roadway sections with various combinations of centerlines, edgelines, PMDs, and RPMs. The difficulty in directly evaluating the safety effectiveness of alternative delineation treatments prompted other studies to evaluate operational measures of effectiveness (MOEs) that are correlated to accident experience and, therefore, could be used as surrogates for accident experience in safety evaluations.

Taylor et al. (*3*) presented the state of the art in roadway delineation systems through 1972, which was the basis for most subsequent research. Operational data were collected with various combinations of centerlines, edgelines, PMDs, and RPMs at two horizontal curve locations. They concluded that RPMs, either alone or in conjunction with PMDs, used as supplements to existing centerlines, improve driver performance through horizontal curves, when compared to weathered painted centerlines.

Stimpson et al. (*4*) performed field studies comparing various combinations of centerlines, edgelines, PMDs, and RPMs at eight sites. They recommended 2- to 4-in. centerline and edgeline striping for continuous delineation on two-lane rural highways. They recommended RPMs to supplement the centerline where severe visibility problems caused by fog or blowing sand are common. For isolated horizontal curves, based on field studies at two locations, they concluded that RPMs are preferred over PMDs as supplements to centerlines. They also stated, however, "When RPMs cannot be used because of economic problems, consideration should be given to the installation of post delineators on the outside of the curve. Although not likely to be as beneficial as RPM supplements, PMDs apparently do provide some degree of near as well as far delineation" (*4*).

Bali et al. (*5*) developed a cost-benefit methodology for evaluating delineation treatments based on safety effectiveness. The continuous delineation treatments studied included various combinations of centerlines, edgelines, PMDs, and RPMs. Treatments for isolated horizontal curves included combinations of centerlines, edgelines, and PMDs. Accident data were obtained for more than 500 sites in 10 states. Regression models were developed to predict accident rates based on roadway, traffic, environmental, and delineation variables. Separate models were developed for tangent and winding alignments and for isolated horizontal curves. For tangent and winding alignments, they found that highways with centerlines had lower accident rates than highways without centerlines, that highways with RPM centerlines had lower accident rates than highways with painted centerlines, and that highways with PMDs had lower accident rates than highways without PMDs (both with and without edgelines). The analysis of the effects of edgelines was inconclusive. In the models for isolated horizontal curves, the type of delineation did not explain accident rate variance.

Capelle (*6*) reviewed roadway delineation research up to 1978 and noted, "Although the literature suggests that RPMs can be a very effective supplemental treatment at curves on two-lane roads, there have been very few studies of the effect of this system." Regarding PMDs, he concluded, "The evidence to date does not permit a positive recommendation of a standard for the use of post delineators as a supplement, but there is sufficient information which indicates that their use can be effective under certain conditions."

In the early 1980s, Niessner (*7,8*) coordinated separate field evaluations of PMDs and RPMs. He concluded, based on field evaluations of PMDs in eight states, "It is not possible to state that the installation of post delineators under all conditions will result in a reduction in the number of run-off-the-road-type accidents. The data that was collected indicates a trend toward reducing this type of accident with the installation of post delineators" (*7*). His finding with respect to RPMs, based on field evaluations in 12 states, was as follows: "The general consensus was that the raised pavement markers do provide improved nighttime pavement delineation when compared to and used in conjunction with conventional paint stripes. However, they should not be construed as a panacea for reducing the potential hazards at all locations" (*8*).

Several other studies have also evaluated the operational effects of RPMs and PMDs at horizontal curves on two-lane highways. Nemeth et al. (*9*) measured the distance from which a curve could be detected with various combinations of centerlines, edgelines, PMDs, and RPMs and found that, compared to no delineation, the addition of RPMs to centerline and edgelines gave the largest increase in detection distance. Zador et al. (*10*) evaluated chevrons, PMDs, and RPMs and found that vehicles moved toward the centerline when PMDs were added but moved away from the centerline when chevrons and RPMs were added. The variability in speeds and lateral placements were slightly reduced when chevrons and RPMs were used.

STUDY APPROACH

This study focused on the short-, intermediate-, and long-term operational effects of replacing the existing PMDs with RPMs supplementing the painted centerline at isolated horizontal curves on two-lane rural highways in Texas. The scope of the study was restricted to two-lane rural highways whose existing delineation consisted of weathered painted centerlines and PMDs on the outside shoulder.

The basic study approach was to focus on operational MOEs that could be observed in the field and that were good surrogates for accident experience. Study sites were selected, and data were collected with the existing PMDs, new PMDs, new RPMs, and weathered RPMs (6 weeks, 10 to 11 weeks, and 11 months old). Data were collected only at night and under clear, dry weather conditions. Statistical analyses were performed to identify the differences in the operational MOEs among the delineation treatments.

Operational Measures of Effectiveness

The study used MOEs that previous research suggests are correlated with accident rates on horizontal curves. The following MOEs were used in the study:

- Speed at the midpoint of the curve,
- Speed change from the beginning to the midpoint of the curve,
- Lateral placement at the midpoint of the curve, and
- Vehicle encroachments into the opposing lane at the midpoint of the curve.

Several researchers have argued that run-off-the-road accidents result from vehicles traveling too fast and, therefore, that it is desirable for delineation treatments to reduce mean speeds (*11,12*). Taylor et al. (*3*), however, found that there was not a statistically significant correlation between accident rates and speed measures including the mean, variance, and skewness of the speed distribution. In spite of Taylor's finding, the mean and standard deviation of speeds at the midpoint of the curves were studied because they are such fundamental measures of traffic operations.

The speed change from the beginning to the midpoint of a curve is a measure of the deceleration within the curve. Taylor et al. (*3*) concluded, "Although strong evidence does not exist in support of the hypothesis that accident rates are correlated with deceleration rates on horizontal curves, there seems to be some justification in concluding that this correlation may also exist. It would seem that delineation treatments that reduce this statistic are ones that provide advance warning of curves." Thompson and Perkins (*13*) also identified the speed differential between the approach and midpoint of the curve as a good surrogate for the accident rate on the outside lane of isolated horizontal curves.

Stimpson et al. (*4*) suggested that the ideal vehicle path is parallel to the centerline and centered on the lane and reported that accident frequencies on tangent and winding alignments are correlated with the variance of lateral placement and with a centrality index that measures the extent to which the mean lateral placement deviates from the center of the lane. Taylor et al. (*3*) found, "A fairly strong correlation between accident rates and the variance of lateral placement on the horizontal curve seems to exist. Thus, if delineation treatments can be shown to reduce the variance in lateral placement, accident rates probably will also be reduced."

The number of vehicle encroachments is related to the variance of the lateral placements. In this study, an encroachment is said to occur if the left front wheel crosses the center of the roadway. Thompson and Perkins (*13*) reported positive correlations between the total encroachment rate (i.e., "number of edgeline plus centerline touches per 100 vehicles entering curve") and accident experience at horizontal curves. A smaller number of encroachments would be indicative of a more effective delineation treatment.

Study Sites

Five horizontal curves were studied. Site selection criteria were as follows:

- Isolated simple circular curve,
- Existing weathered painted centerlines and PMDs, but no edgelines,
- Speed limit of 45 mph or higher,
- Shoulders, if present, no wider than 4 ft,
- Minimal roadside development and, therefore, low nighttime ambient light level,
- Few, if any, intersecting driveways in the vicinity of the site, and
- Average annual daily traffic (AADT) of at least 2,000 vehicles per day.

Table 1 shows the characteristics of the curves that were studied. The degree of curvature ranged from 3 to 5 degrees, curve lengths from 850 to 1,670 ft, and pavement widths from 19 to 28 ft. All of the sites had weathered painted centerlines and PMDs on the outside of the curve. None of the curves had edgelines.

Delineation Treatments

Table 2 shows the delineation treatments studied at each site. Treatments were monitored in essentially the same sequence at all sites. During the first evening at a site, data were collected with the existing PMDs. During the next day, the PMDs were removed and new RPMs were installed. During the second evening, data were collected with the new RPMs. At two sites (FM 219 and FM 933), new delineators were placed on the posts and data were collected with the new PMDs during the second evening. At these sites, the new PMDs were removed during the third day and new RPMs were installed, and data were collected with the new RPMs during the third evening. Also at these sites, follow-up studies were conducted to monitor vehicle operations after the RPMs had been in place 6 weeks and again after 10 to 11 weeks. At the FM 1753 study site, data were collected after the RPMs had been in place 11 months.

Data Collection Procedures

The speeds and lateral placements of vehicles were measured at the beginning, midpoint, and end of the horizontal curve. Data were collected in both lanes at each location.

An automated data collection system with tapeswitches as axle sensors was used. As each vehicle axle crossed a tapeswitch, an electronic impulse was transmitted to a Golden River environmental computer. The computer recorded the time and a code for which tapeswitch was actuated, from which speeds and lateral placements were computed.

The tapeswitches were covered with a flat gray material that blended with the roadway surface. Their ¼-in.-high profile caused a barely audible rumble within vehicles passing over them. Observations of drivers passing over the tapeswitches in a previous study showed no noticeable effect on driver behavior (*14*).

Statistical Analysis Methodology

The statistical analysis was performed to identify any differences in the operational MOEs at the curves between the

TABLE 1 GEOMETRICS OF STUDY SITES

Site	AADT	Degree of Curvature	Length of Curve (ft)	Pavement Width (ft)
FM 1753	2700	5	1020	20
FM 730	1650	3	1670	19
FM 2280	3700	3	1110	22
FM 219	1350	5	850	28
FM 933	1350	4	890	25

TABLE 2 DELINEATION TREATMENTS TESTED AND SAMPLE SIZE

Site	Existing PMDs	New PMDs	New RPMs	6-Week-Old RPMs	10-11-Week-Old RPMs	11-Month-Old RPMs
FM 1753	52	--	33	--	--	27
FM 730	8	--	24	--	--	--
FM 2280	62	--	34	--	--	--
FM 219	28	28	31	28	35	--
FM 933	47	50	56	46	35	--

existing PMDs and new RPMs, and between new RPMs and RPMs that had lost some of their retroreflectivity.

The data base was screened to include only those vehicles that could be tracked through the entire study section and whose operations were unaffected by other vehicles. Vehicles that could not be tracked included vehicles on the curve when data collection began and ended or vehicles that left the roadway at driveways within the study section. Vehicles were considered to be unaffected by other vehicles if they were neither closely following another vehicle in their lane nor within the study section at the same time as a vehicle in the opposing lane. Drivers closely following other vehicles receive visual cues from the leading vehicle as well as from the roadway delineation; therefore, vehicles were removed from the data base if their headway was 4 sec or less. Illumination from the headlights of oncoming vehicles affects driver behavior; therefore, vehicles were also removed from the data base if they were within the study section during the same time as a vehicle in the opposing lane.

Prior to data collection, it was estimated that a sample size of approximately 50 vehicles would be required with each treatment at each site in order to be reasonably confident of detecting a 2-mph difference in mean speeds and 0.5-ft difference in mean lateral placements. Table 2 shows the actual number of vehicles in the data base for each treatment and site. The total sample size was 624. For all but one site, the data base included at least 25 vehicles for each treatment.

Analyses were performed to evaluate the short-, intermediate-, and long-term operational effectiveness of RPMs. The statistical analyses were performed separately for each MOE at each study site. A 0.05 significance level was used for all tests. The short-term analysis (existing PMDs versus new RPMs) compared the mean speed at the midpoint, speed change from the beginning to the midpoint, and lateral placement at the midpoint using *t*-tests. The standard deviations of these MOEs were compared using *F*-tests. The number of encroachments was analyzed using a chi-squared test. The intermediate-term effectiveness of the 6 to 11-week-old RPMs and long-term effectiveness of the 11-month-old RPMs also involved separate analyses of each MOE at each site. A single-factor analysis of variance (ANOVA) was performed to compare the speed and lateral placement MOEs with the various treatments at each site. If the ANOVA results suggested that differences existed, then a pairwise (least-significant difference) *t*-test was performed to determine which treatments were significantly different.

Separate analyses were performed for the inside and outside lanes of the curves. Previous research indicates that the run-off-the-road accident problem and the delineation requirements are greater on the outside lane than on the inside lane of a horizontal curve (*2*). The painted centerline is better illuminated by vehicles traveling on the inside lane and satisfies most of the guidance requirements. As a result, vehicle operations on the inside lane of a curve would be expected to be less affected by replacing PMDs with RPMs than on the outside lane. Indeed, no differences between the PMDs and RPMs were observed on the inside lane of the curves studied. Therefore, only results for the outside lane are presented here. Results for the inside lane are reported elsewhere (*15*).

ANALYSIS RESULTS

Short-Term Operational Data Analysis

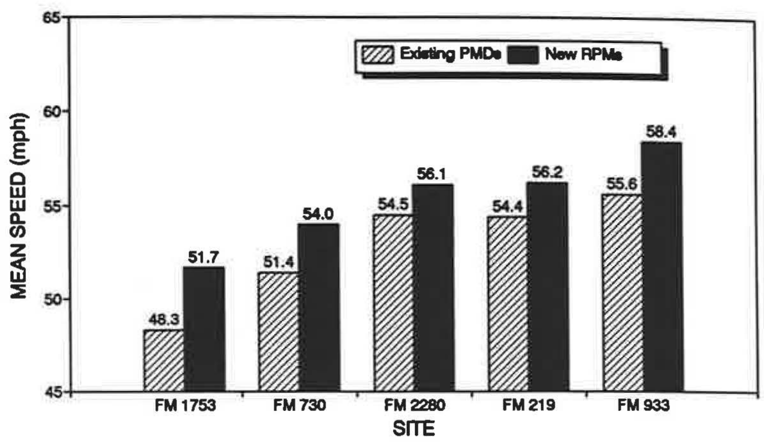
Figure 1 shows that the mean speeds with the new RPMs are consistently 1 to 3 mph higher than with the existing PMDs. The *t*-test results indicate that the differences in mean speeds between the two treatments were statistically significant only at the FM 1753 and FM 933 sites. The *F*-test results indicate that the standard deviation of speeds with the two treatments did not differ significantly at any of the sites. It is not clear whether the higher speeds with the new RPMs are good or bad. Allen et al. (*16*) found that drivers' preferred speed increases as their visual range increases. So, higher speeds may indicate that the new RPMs provided better delineation than the existing PMDs and that drivers had more confidence traveling through the curves. Others argue that speeds are a factor in run-off-the-road accidents and that it is desirable to reduce speeds at curves (*12,13*). However, previous research has not found a correlation between speeds and accident rates with different delineation treatments (*3*).

The speed change from the beginning to the midpoint of the curve was computed for each vehicle as the vehicle's speed at the midpoint minus the speed at the beginning of the curve. Therefore, a negative speed change indicates that the vehicle decelerated from the beginning to the midpoint of the curve, and a positive speed change indicates that the vehicle accelerated. Figure 2 shows the mean and standard deviation of the speed changes at each study site. There were no statistically significant differences in either the means or standard deviations for the two treatments at any of the sites.

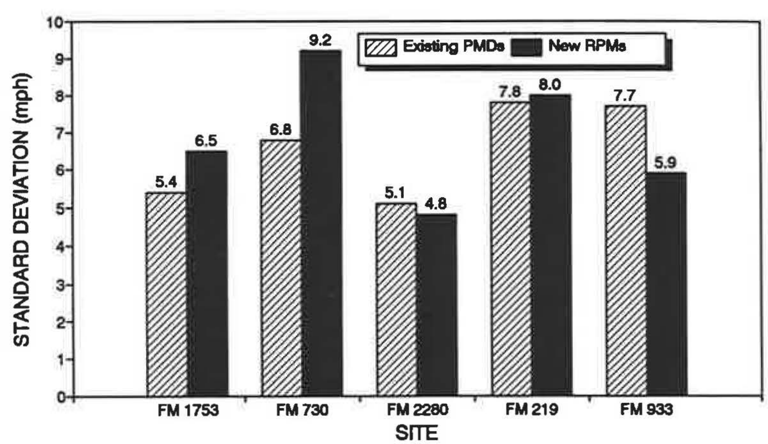
Lateral placement was measured at the midpoint of the curve from the center of the roadway to the outside edge of the left front wheel of the vehicle. As shown in Figure 3, the mean lateral placement with the new RPMs was at least 0.9 ft further from the center of the roadway than with the existing PMDs at all of the study sites. The mean lateral placement was significantly greater with the new RPMs than with the existing PMDs at all but the FM 730 site. These results demonstrate that motorists are less inclined to flatten their path through horizontal curves with RPMs than with PMDs. Previous research has suggested that the ideal vehicle path is centered in the lane. Therefore, these results suggest that the new RPMs compare favorably with the existing PMDs. The standard deviation of lateral placement was smaller with the new RPMs than with the existing PMDs at four of the five sites. The differences were statistically significant at the FM 1753 and FM 730 sites. Previous research suggests that a smaller variance in lateral placement tends to be associated with lower accident rates. Therefore, the new RPMs compare favorably to the existing PMDs with respect to this MOE.

Figure 4 shows the percentage of vehicles in the outside lane that crossed the center of the roadway at the midpoint of the curve. There were fewer encroachments with the new RPMs than with the existing PMDs at all of the sites. The differences between the treatments were statistically significant at all sites except FM 219.

The short-term data analysis suggests that drivers operated differently in the outside lane of horizontal curves when the existing PMDs were replaced with new RPMs supplementing

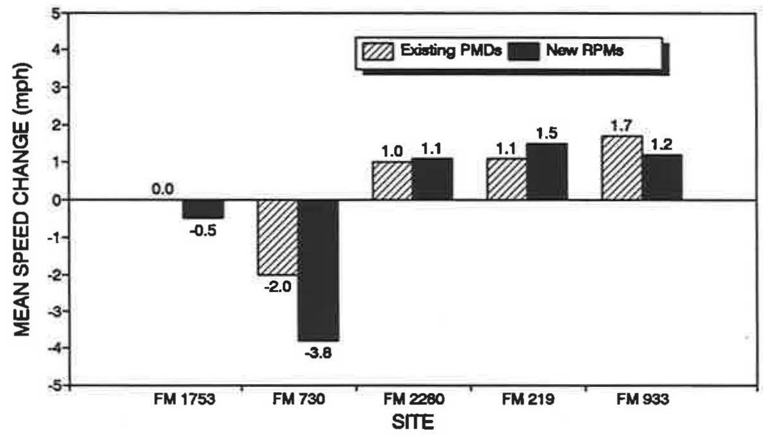


(a) Mean Speeds

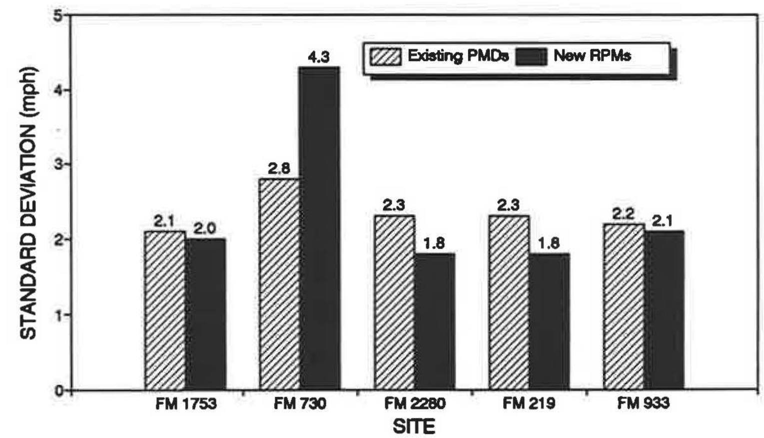


(b) Standard Deviation of Speeds

FIGURE 1 Speeds at midpoint of curve: short-term.

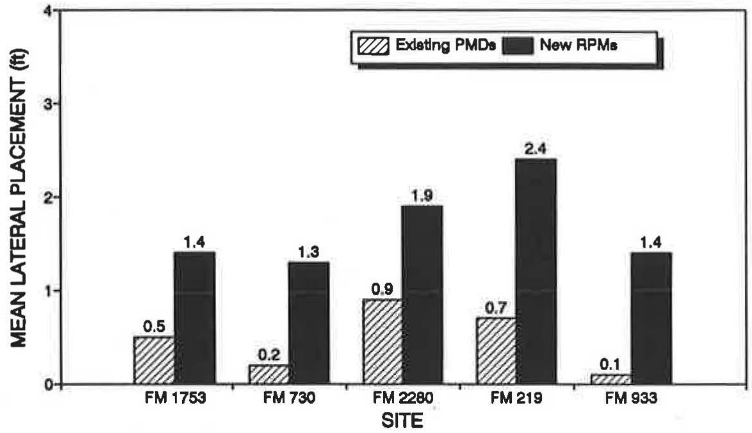


(a) Mean Speed Changes

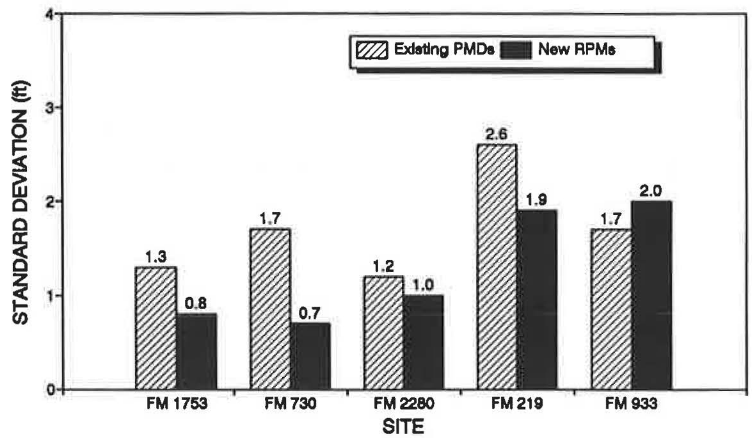


(b) Standard Deviation of Speed Changes

FIGURE 2 Speed changes from beginning to midpoint of curve: short-term.



(a) Mean Lateral Placements



(b) Standard Deviation of Lateral Placements

FIGURE 3 Lateral placements at midpoint of curve: short-term.

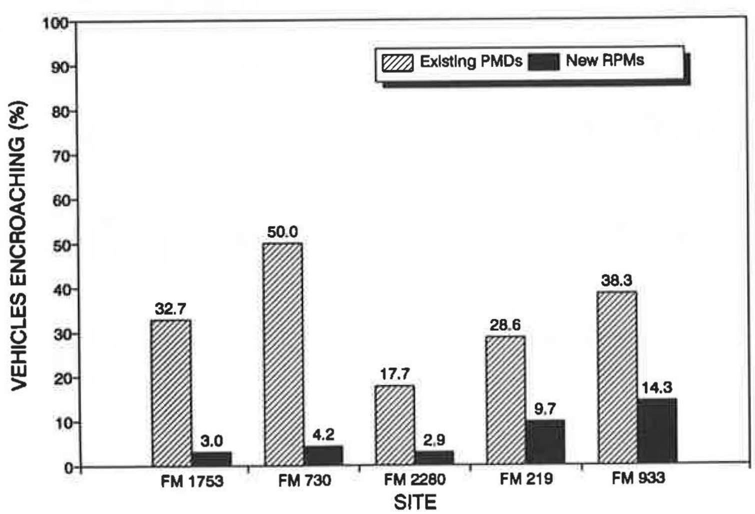


FIGURE 4 Percentage of vehicles encroaching into opposing lane at midpoint of curve: short-term.

the existing painted centerline. The following differences were observed:

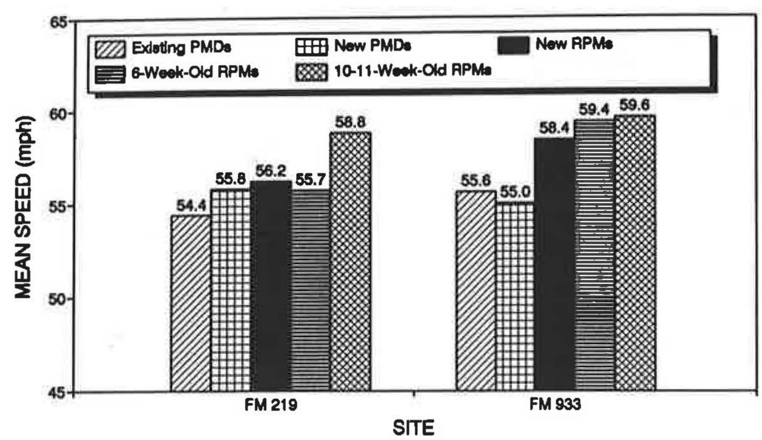
- The mean speeds at the midpoint of the curves were consistently 1 to 3 mph higher with the new RPMs than with the existing PMDs.
- The mean lateral placement was consistently 1 to 2 ft further from the center of the roadway at the midpoint of the curve with the new RPMs than with the existing PMDs.
- There was less variability in lateral placement at the midpoint of the curve with the new RPMs than with the existing PMDs.
- Fewer vehicles crossed the center of the roadway with the new RPMs than with the existing PMDs.

Overall, operations with the new RPMs compare favorably with the existing PMDs. The results suggest that the change in delineation treatments did not cause any operational problems and that the new RPMs provided better path delineation (as evidenced by the findings related to lateral placement and encroachments), which may have given drivers the confidence to operate at higher speeds through the curves.

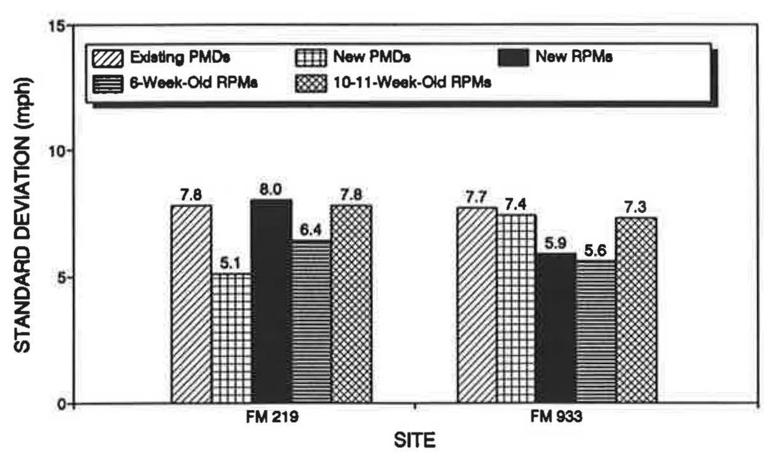
Intermediate-Term Operational Data Analysis

At two sites, follow-up field studies were conducted to monitor changes in vehicle operations through the curves after the RPMs had lost some of their retroreflectivity. Five delineation treatments were monitored at the FM 219 site: existing PMDs, new PMDs, new RPMs, 6-week-old RPMs, and 11-week-old RPMs. Retroreflectivity measurements (at a 20-degree incidence angle) for the 6-week-old and 11-week-old RPMs, 2.4 and 2.1 candlepower per foot candle (cp/ft-c), respectively, exceeded the 2.0 cp/ft-c initial-brightness specification for new RPMs in Texas. The delineation treatments at the FM 933 site were similar: existing PMDs, new PMDs, new RPMs, 6-week-old RPMs (with 2.1 cp/ft-c), and 10-week-old RPMs (with 1.0 cp/ft-c).

The speeds observed in the outside lane at the FM 219 and FM 933 sites are shown in Figure 5. The ANOVA results for the FM 219 site indicate that none of the treatments had significantly different mean speeds. The results of the single-factor ANOVA and pairwise *t*-test for the FM 933 site indicate that (*a*) the mean speeds with the three RPM treatments were not significantly different, (*b*) the mean speeds with the two



(a) Mean Speeds



(b) Standard Deviation of Speeds

FIGURE 5 Speeds at midpoint of curve: intermediate-term.

PMD treatments were not significantly different, but (c) the mean speeds were significantly higher with the RPM treatments than with the PMD treatments.

Figure 6 shows that the mean speed increased from the beginning to the midpoint of the curve. At the FM 219 site, the mean speed increase with the 11-week-old RPMs was significantly greater than with either the existing or the new PMDs, but none of the other pairs of treatments were significantly different. At the FM 933 site, none of the treatments differed significantly.

The lateral placement at the midpoint of the curve is shown in Figure 7 for the FM 219 and FM 933 sites. The mean lateral placements with all of the RPM treatments were significantly greater than with any of the PMD treatments at both sites.

Figure 8 shows that the percentage of vehicles encroaching was less for the RPM treatments than for the PMD treatments at both the FM 219 and FM 933 sites. The results of the chi-squared tests indicate that the differences among the treatments were statistically significant.

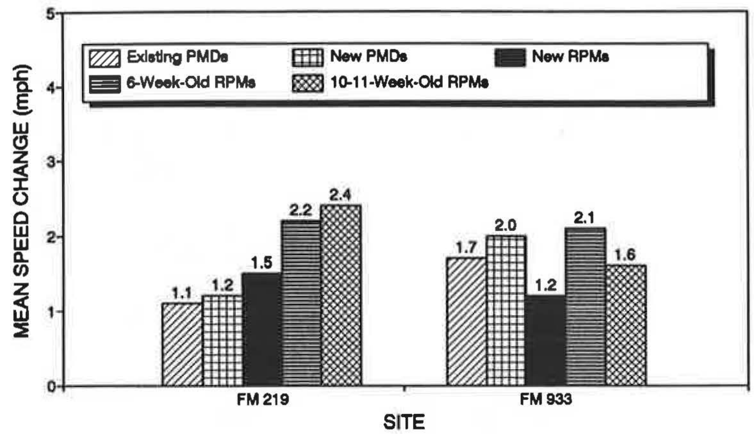
Few changes in the operational effectiveness of RPMs were observed as the RPMs aged and lost some of their retroreflectivity. At the FM 219 and FM 933 sites, little reduction in retroreflectivity was observed, and vehicle operations changed very little up to 11 weeks after the new RPMs were installed. Therefore, the results at the FM 219 and FM 933 sites reinforce the findings of the short-term analysis.

Long-Term Operational Data Analysis

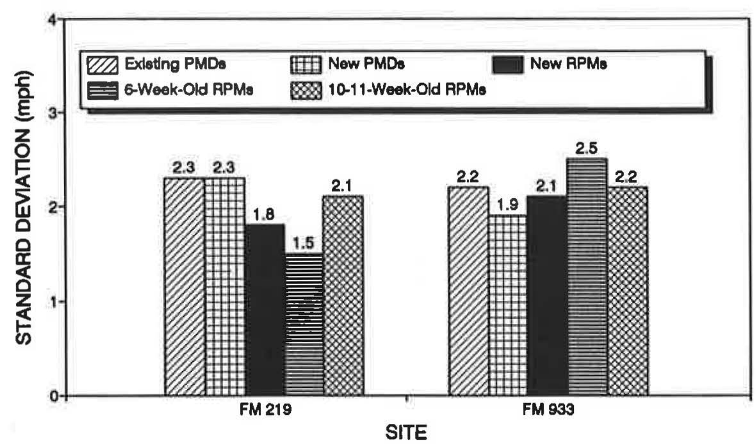
Vehicle operations were monitored at the FM 1753 site after the RPMs had been in place 11 months. The mean specific intensity of the RPMs at that time was 0.1 cp/ft-c.

The delineation treatments at the FM 1753 site were the existing PMDs, new RPMs, and 11-month-old RPMs. Figure 9 shows the mean and standard deviation of the speeds with each treatment. The single-factor ANOVA and pairwise t-tests results indicate that the mean speed with the new RPMs was significantly higher than with either the existing PMDs or the 11-month-old RPMs, but that the latter two did not differ significantly.

The means and standard deviations of the speed change with the three treatments at the FM 1753 site are shown in

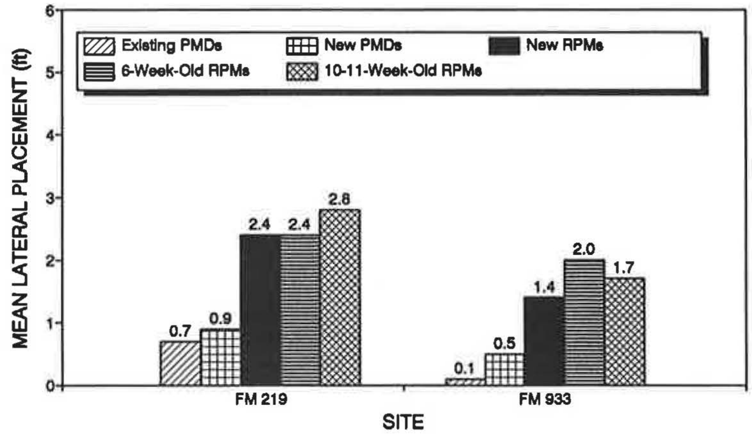


(a) Mean Speed Changes

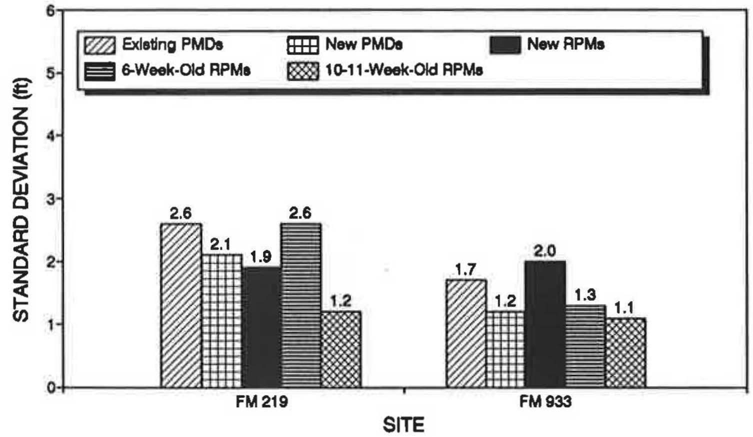


(b) Standard Deviation of Speed Changes

FIGURE 6 Speed changes from beginning to midpoint of curve: intermediate-term.



(a) Mean Lateral Placements



(b) Standard Deviation of Lateral Placements

FIGURE 7 Lateral placements at midpoint of curve: intermediate-term.

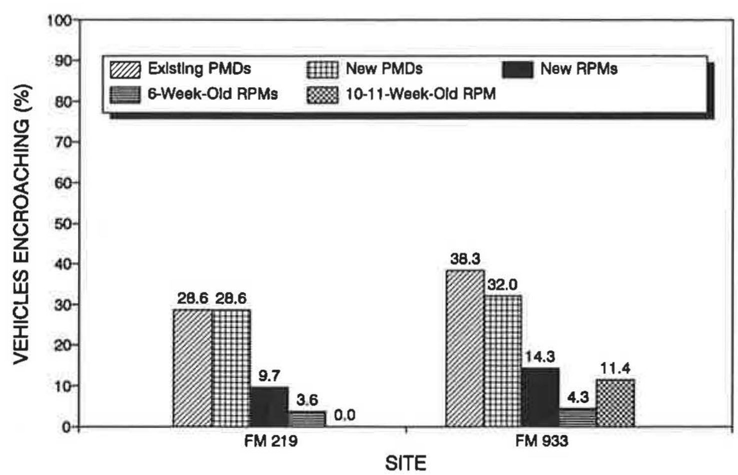
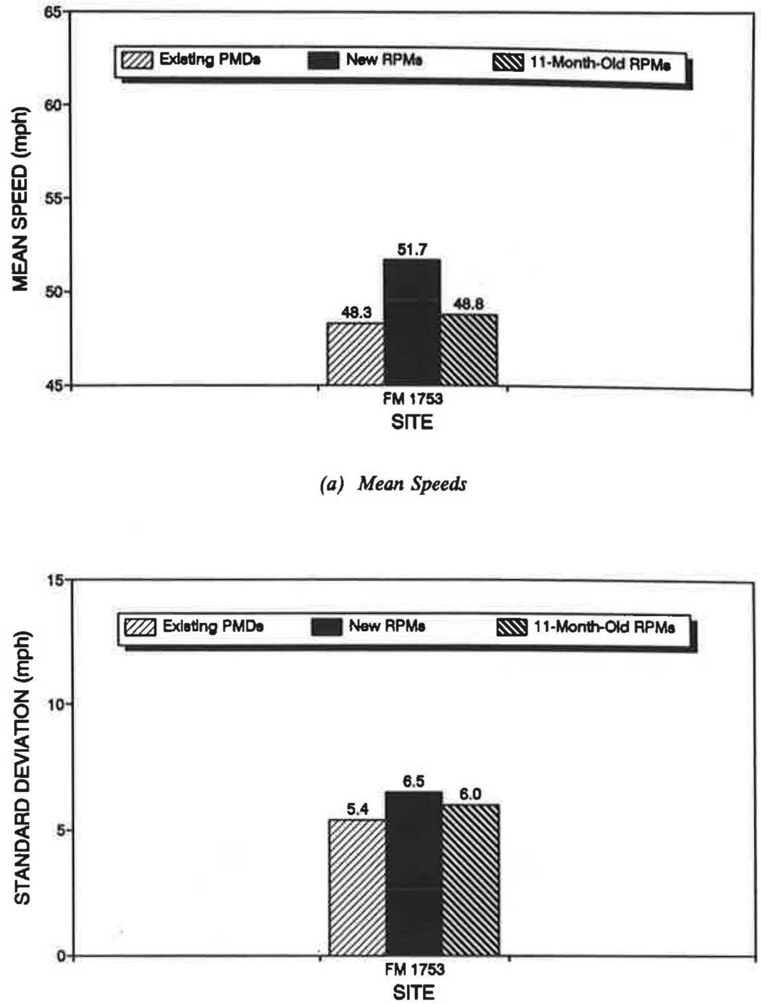


FIGURE 8 Percentage of vehicles encroaching into opposing lane at midpoint of curve: intermediate-term.



(a) Mean Speeds

(b) Standard Deviation of Speeds

FIGURE 9 Speeds at midpoint of curve: long-term.

Figure 10. The mean speed reduction with the 11-month-old RPMs was significantly greater than with either the existing PMDs or new RPMs, but the latter two did not differ significantly.

Summary statistics for the lateral placement at the midpoint of the curve are shown in Figure 11 for the FM 1753 site. The mean lateral placement with both the new and 11-month-old RPMs was greater than with the existing PMDs, but the two RPM treatments were not significantly different.

Figure 12 shows that the proportion of vehicles encroaching was less with the RPM treatments than with the existing PMDs. The results of the chi-squared tests indicate that the differences among the treatments were statistically significant.

The 11-month-old RPMs at the FM 1753 compared favorably with the existing PMDs and were similar to the new RPMs with respect to the mean lateral placement and the number of encroachments. These results suggest that the RPMs, in spite of their loss of retroreflectivity, continued to provide adequate near delineation. The mean speed at the midpoint of the curve with the 11-month-old RPMs was the same as with the existing PMDs but was significantly lower than with the new RPMs. These results are an indication of the relative visual range provided by the treatments. The only MOE that caused concern with the 11-month-old RPMs was a small but statistically significant increase in deceleration from the beginning to the midpoint of the curve. This increase suggests that the RPMs' effectiveness at providing far delineation was somewhat degraded. Unfortunately, there is no objective basis for determining whether the far delineation provided by the 11-month-old RPMs was adequate.

The results from the FM 1753 site suggest that the operational effectiveness of RPMs is due in part to their retroreflectivity and in part to their profile above the pavement surface. Even with low retroreflectivity, it appears that the RPMs continue to serve at least part of their intended function because of their profile.

SUMMARY AND RECOMMENDATIONS

The operational effectiveness of RPMs as an alternative to PMDs at horizontal curves on two-lane rural highways was

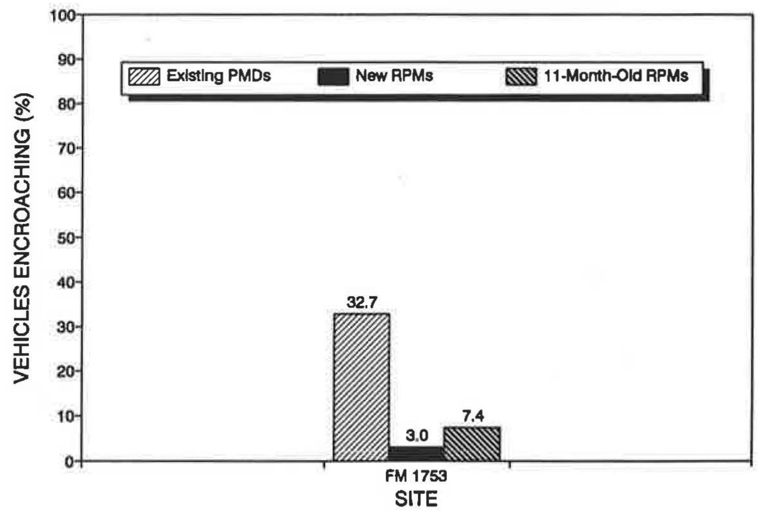


FIGURE 12 Percentage of vehicles encroaching into opposing lane at midpoint of curve: long-term.

evaluated based upon nighttime speed and lateral placement data at five horizontal curves. The analysis focused on those MOEs that previous research suggests are correlated to accident rates at horizontal curves.

The statistical analysis of the short-term operational data suggested that vehicle operations on the inside lane of the curves were not significantly affected by the removal of the PMDs and installation of new RPMs. However, several significant differences were observed on the outside lane of the curves. The mean speeds at the midpoint of the curves were consistently 1 to 3 mph higher with the new RPMs than with the existing PMDs. The mean lateral placement was consistently 1 to 2 ft further from the center of the roadway at the midpoint of the curves with the new RPMs than with the existing PMDs. The variability in lateral placement at the midpoint of the curve was less with the new RPMs than with the existing PMDs. Fewer vehicles crossed the center of the roadway with the new RPMs than with the existing PMDs. The short-term evaluation suggests that the new RPMs provided better path delineation (as evidenced by the findings related to lateral placement and encroachments), which may have given drivers the confidence to operate at higher speeds through the curves.

Intermediate-term operational data were collected at two sites. Data were collected after the RPMs had been in place 6 weeks and again after 10 to 11 weeks. The RPMs retained much of their retroreflectivity at these sites, and the results of the data analysis reinforce the findings of the short-term evaluation.

At one site, data were collected after the RPMs had been in place 11 months and had lost much of their retroreflectivity (mean specific intensity of 0.1 cp/ft-c). The mean lateral placement and number of encroachments with the 11-month-old RPMs were not significantly different than with the new RPMs and compared favorably with the PMDs. The fact that the mean speed at the midpoint of the curve with the 11-month-old RPMs was similar to the existing PMDs but less than with the new RPMs is an indication of the relative visual range provided by the treatments. The only MOE that caused concern with the 11-month-old RPMs was the small, but statistically significant, increase in deceleration from the beginning to the midpoint of the curve, which may indicate that motorists did not receive sufficient advance warning of the curve. These results suggest that after 11 months the RPMs continued to provide near delineation but that their far delineation was at least partially degraded.

There is no objective basis for defining minimum performance levels for RPMs. Because previous research has not addressed the long-term effectiveness of RPMs and because this study involved a long-term evaluation at only one site, additional research would be necessary to determine at what point RPMs no longer function adequately (i.e., the service life of RPMs). It would be desirable to determine how the operational effectiveness of RPMs changes as they lose retroreflectivity and to define a minimum performance level in terms of the operational MOEs used here.

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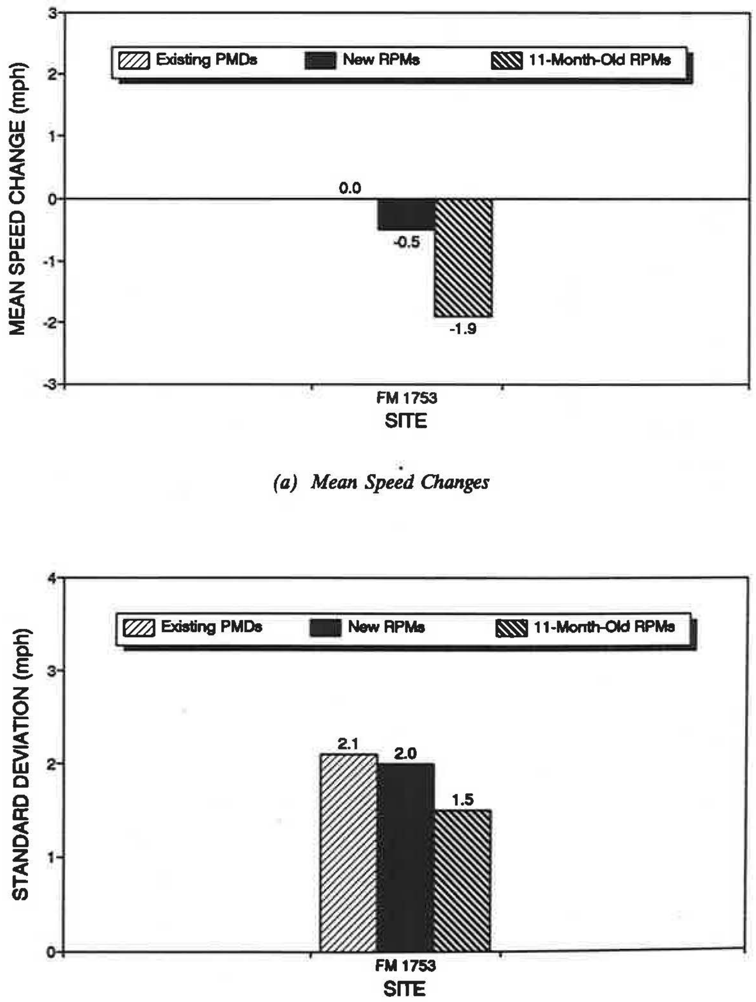
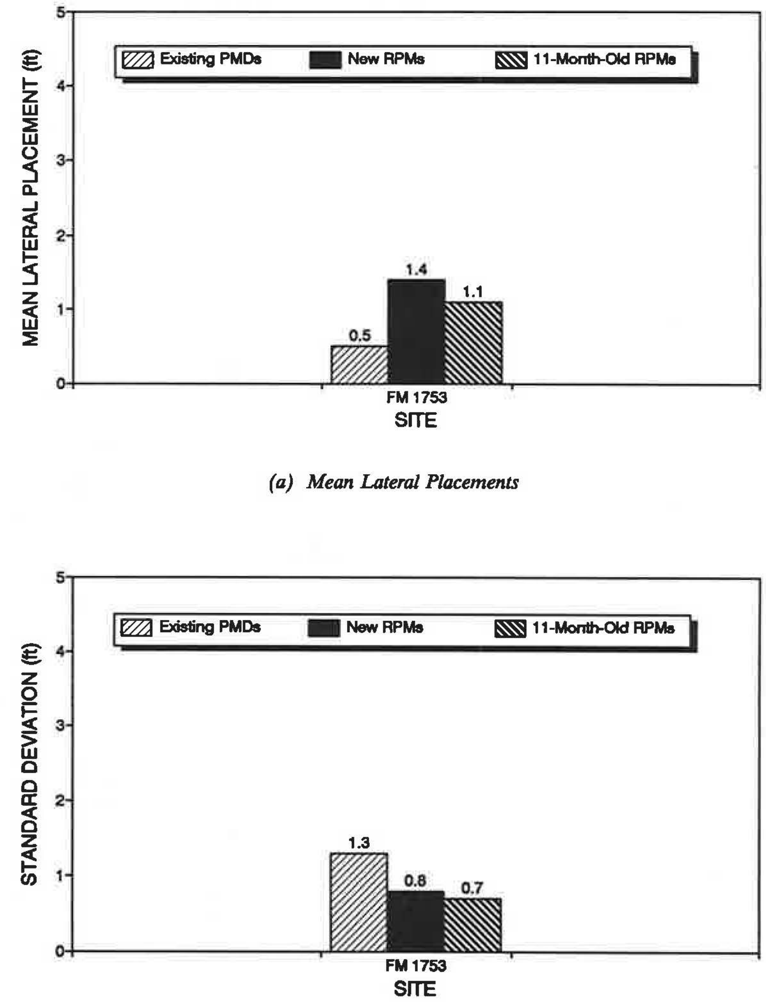


(a) Mean Speed Changes

(b) Standard Deviation of Speed Changes

FIGURE 10 Speed changes from beginning to midpoint of curve: long-term.



(a) Mean Lateral Placements

(b) Standard Deviation of Lateral Placements

FIGURE 11 Lateral placements at midpoint of curve: long-term.

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