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EVALUATION OF THE SAFETY EFFECTS OF RAISED PAVEMENT MARKERS

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DISCLAIMER

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CHAPTER I. INTRODUCTION

The Pavement Marking Demonstration Program, authorized under the Highway Safety Act of 1973, provided funds to the States for the purpose of installing and improving highway delineation treatments. In a number of States, portions of these funds were used to install raised reflective pavement markers (RPM's) as a supplement to striping. This treatment was judged to be conducive to safer highway driving because the reflective properties of the markers were believed to provide drivers with better feedback for vehicle guidance at night or in inclement weather. Although the benefits of raised pavement markers in enhancing visibility at night and in inclement weather have been widely recognized, few evaluations have been conducted to examine whether the markers are actually effective in reducing accidents.

In 1982, the Texas Transportation Institute (TTI), in cooperation with the Texas State Department of Highways and Public Transportation (SDHPT), conducted a study to evaluate the effectiveness of RPM's in reducing accidents in Texas (Kugle, Pendleton, and Von Tress, April 1984). The study reviewed accident histories at 469 locations where RPM's had been installed between 1977 and 1979. These 469 locations were drawn from 22 projects in 100 Texas counties. The lengths of the locations ranged from 0.2 to 24.5 miles. Sixty-five percent of the locations were on two-lane roadways; 33 percent on four-lane roadways; and two percent on three-lane, five-lane, or six-lane roadways.

Kugle et al. assessed changes in nighttime accidents between the before and the after periods, relative to changes in daytime accidents. In other words, daytime accidents were used as a comparison condition for nighttime accidents. Daytime accidents included those occurring in daylight, dawn, and dusk. Nighttime accidents included those occurring under darkness regardless of street lighting.

Of the 469 locations, 17 were found to have been resurfaced after the RPM installations and, thus, were excluded from the analysis. Accidents from the remaining 452 sites were then combined. Total nighttime accidents from these sites were found to have increased by 15 percent while total daytime accidents were found to have decreased by 1.4 percent. Relative to daytime accidents, nighttime accidents were found to have increased significantly ($p < 0.0001$, where p is the level of confidence). When accidents from all 452 sites were categorized by head-on, sideswipe, ran-off-road, and "preventable" accidents, the increases in nighttime accidents were found to be statistically significant for both ran-off-road and "preventable" accidents (p's < .0001), and were marginally significant for head-on and sideswipe accidents (p's of .05 and .04, respectively). When the accidents were categorized by severity, i.e., fatal, injury, and property-damage-only (PDO) accidents, statistically significant increases were found for both injury and PDO accidents (p's < .0001).

Kugle et al. also pointed out that, although 56 percent of the locations studied showed decreases in nighttime accidents after the RPM installations, 10 percent showed very high increases in nighttime accidents after the RPM installations. It was the large increases in nighttime accidents at these locations that resulted in the overall increase in nighttime accidents for all locations combined.

In the months since publication of the Kugle et al. report, several recommendations were made with regard to extending the original study and improving the data base used in the original analyses. Concern has been expressed that many of the 469 locations in the earlier study may have undergone major improvements or modifications during the study period. If such was the case, then any calculated effect of RPM's on accident frequency and/or severity could be confounded with the effects of highway improvements or modifications.

The present study has sought to screen the original data base of 469 locations and to eliminate all of those locations that underwent major improvements or modifications that might have affected accident frequency or severity.

The objectives of the present study were, specifically:

1. To screen the 469 locations in the original study and eliminate any locations that underwent major construction and/or improvements other than the RPM installations during the evaluation period, and
2. To reassess the effect of the RPM's on accident frequency and accident severity.

A brief description of the study approach is presented in Chapter II. Highlights of the study findings and results are summarized in Chapter

III. Finally, conclusions and recommendations are presented in Chapter IV. Data that are too cumbersome for inclusion in the main report are included as an Appendix for reference purposes.

CHAPTER II. STUDY APPROACH

The study approach was designed in accordance with the study objectives. The major activities undertaken in the study included:

1. Data screening,
2. Collection of supplemental data,
3. Data analysis.

More detailed descriptions of these activities are presented in the following sections.

Data Screening

Using records maintained by the Design Division (D-8) of the SDHPT, the construction history for all 469 locations included in the previous study was reviewed manually. The information was then used in the screening of the locations using the following eligibility criteria:

1. All locations for which one or more of the following construction items appeared during any time within the four-year study period were eliminated:
   (a) Hot-mix asphalt pavement (HMAP)
   (b) Asphalt concrete pavement (ACP)
   (c) Two-course surface treatment
   (d) One-course surface treatment
   (e) Installation of traffic signals
   (f) Addition of traffic lane(s)
   (g) Major channelization improvements
   (h) Lane widening
2. Of the remaining locations, those to which the following work items were implemented in the after period were eliminated:
   (a) Seal coat
   (b) Level up
   (c) Surfacing
   (d) Thermoplastic edgelines
   (e) Pavement marking
   (f) Delineation
   (g) Illumination

Of the 469 locations, only 106 locations were found to meet the above eligibility criteria and were included for further analysis. A breakdown of the 106 eligible locations is as followed:

1. 38 locations showed no work done in both the before and after periods;
2. 31 locations showed either seal coat, surfacing, or leveling up during the RPM installations or in the before period;
3. 19 locations showed edgelines improvements during the RPM installations or in the before period;
4. Five locations showed modifications to traffic signals/flashing lights, signing, seal coats for shoulders, landscaping, or replanked timber crossings;
5. Three locations had only about 20 months (instead of 24 months) of clean data in the before period;
6. Three locations had only about 21 months of clean data in the after periods; and
7. Seven locations showed non-contiguous milepoints within locations, indicating discontinuity within these locations.

Also, an examination of accident records for these 106 eligible locations revealed that three locations had no accidents reported for the entire four-year study period, and two other locations had very different numbers of months between the before and the after periods for which the accident data were available. These five locations were thus eliminated, leaving 101 locations for detailed analysis.

Collection of Supplemental Data

In an effort to identify roadway characteristics that may affect the influence of RPM's on accident frequency and severity, the following roadway characteristics were manually coded from the roadway inventory file (RI-1-LOG) for each 0.1 milepoint within selected locations:

1. Urbanization
   - Outside city limit
   - Within city limit
2. Number of lanes
3. Divided/Undivided
   - Undivided
   - Divided

4. Intersection
    - None
    - Interchange
    - T-intersection
    - 4-leg intersection
    - Multiple intersection
5. Degree of curvature
    - Less than 1 degrees
    - 1 to 3 degrees
    - Greater than 3 degrees
6. Grade
    - 3 percent or less
    - Greater than 3 percent
7. Structures
    - None
    - Culvert
    - Bridge

These seven roadway variables were then merged with the accident variables from the accident file for further analysis.

Data Analysis

A location-based approach was used in analyzing the data in this study that was somewhat different from the accident-based approach used in the previous study. In other words, the data analysis centered around individual locations or sites instead of accidents.

The effect of RPM's on accident frequency for individual locations was first evaluated, followed by that on accident severity. Locations showing significant changes, both increases and decreases, in accident frequency and severity were then further analyzed in an attempt to identify accident and/or roadway characteristics that might have contributed to the effects of RPM's on accident frequency and severity. Highlights of the analysis results are presented in the next chapter.

CHAPTER III. STUDY FINDINGS AND RESULTS

The study findings and results are organized under the following major headings:

1. Effect of RPM's on accident frequency,
2. Effect of RPM's on accident severity,
3. Accident characteristics of selected RPM locations, and
4. Roadway characteristics of selected RPM locations.

Only summaries of the more significant study findings and results are presented in this chapter. Additional details of the data are included in the Appendix for reference purposes.

Effect of RPM's on Accident Frequency

For each of the 101 locations, two years of "before" and two years of "after" accident data were analyzed. There were six locations that had slightly fewer than 24 months of accident data in the before or after periods, as described earlier. Accident data for fewer than 24 months, but for equal numbers of months in the before and after periods, were used for each of these six locations.

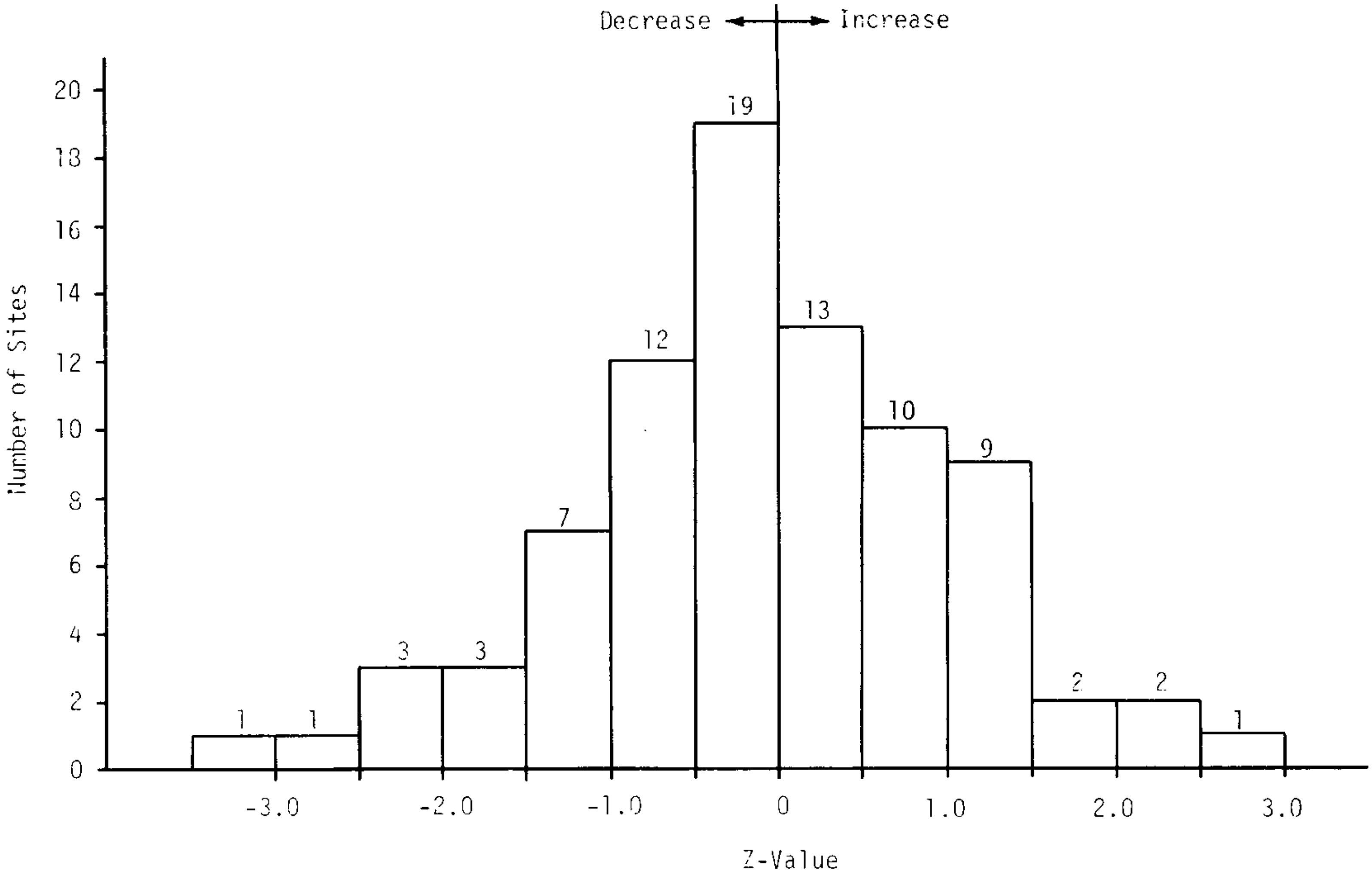
For each location, a two-way contingency table of accidents cross-classified by before/after and daytime/nighttime, was generated. Daytime accidents were defined as those occurring during hours of light and nighttime accidents were defined as those occurring during hours of darkness, with or without street lighting. Accidents that occurred during dusk and dawn (which accounted for only two to three percent of total accidents) were not included in the evaluation. A typical two-way table of accident frequency is shown below.

	Time of Accident	
Study Period	Daytime	Nighttime
Before	X_{11}	X_{12}
After	X_{21}	X_{22}

where:

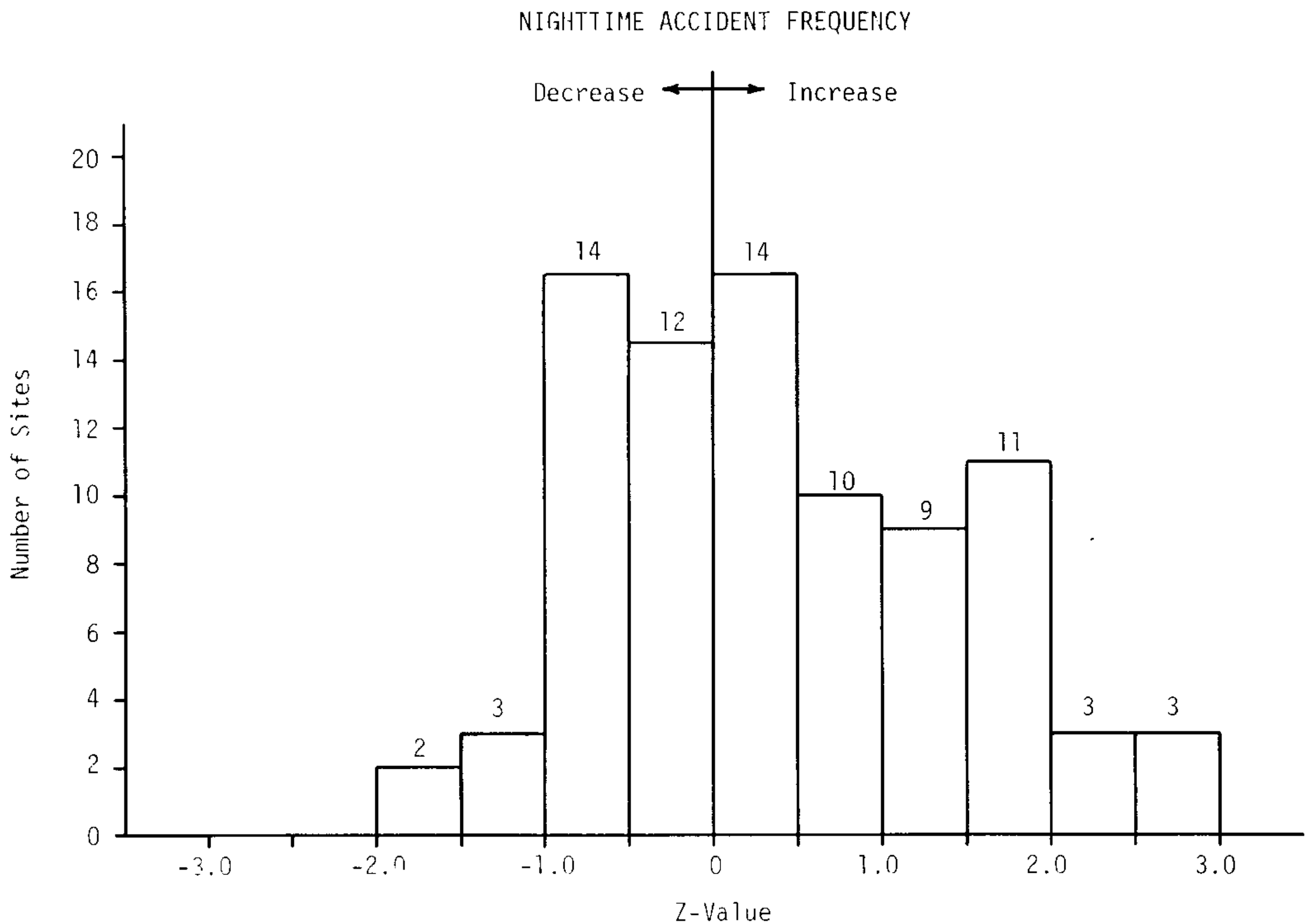
X_{11} = accidents occurring in daylight in the before period,
X_{12} = accidents occurring in darkness in the before period,
X_{21} = accidents occurring in daylight in the after period, and
X_{22} = accidents occurring in darkness in the after period.

DAYTIME ACCIDENT FREQUENCY



*NOTE: There are 4 sites with no change (Z=0)

Figure 1A. Distribution of Accident Index by Location for Daytime Accident Frequency.



*NOTE: There are 6 sites with no change (Z=0)

Figure 1B. Distribution of Accident Index by Location for Nighttime Accident Frequency.

Preliminary analysis of accident data at these 101 locations revealed that 14 locations had at least one cell with no accidents (i.e. X_{11}, X_{12}, X_{21}, or X_{22} was zero). Most of these 14 locations had four or fewer accidents in the before or after period. Statistical analysis of these locations individually would not yield meaningful results. These locations were thus not included in further statistical analyses, leaving 87 locations for statistical tests at the individual-site level.

An accident index to measure changes in accident frequencies at individual sites after the RPM installations was defined as:

$$\mathbf{Z} = \frac{X_{2i} - X_{1i}}{X_{2i} + X_{1i}}$$

where:

Z = an accident index

X_{2i} = accidents in the after period for the i-th condition (1 = daytime; 2 = nighttime)

X_{1i} = accidents in the before period for the i-th condition (1 = daytime; 2 = nighttime)

This accident index, Z, is normally distributed with a mean of zero and variance of 1. A positive value of Z indicates an increase in accidents from the before to the after period for that particular location. Conversely, a negative value of Z indicates a reduction in accident frequency from the before to the after period for that location. A zero value of Z indicates no change in the number of accidents between the before and after periods for that location.

Two values of Z were calculated for each of the 87 locations, one for daytime (i = 1) and the other for nighttime (i = 2). The values for all 87 locations were plotted separately for daytime and for nighttime, as shown in Figures 1A and 1B, respectively. For daytime, 37 (42.5%) locations showed increases in accidents, 46 (52.9%) locations showed decreases, and 4 (4.6%) showed no change in accidents. For nighttime, 50 (57.5%) locations showed increases in accidents, 31 (35.6%) showed decreases, and six (6.9%) showed no change.

Since there were no "control" locations (i.e., similar highway segments that had no RPM installations) available for evaluation purposes, a "comparison" group had to be defined for the analysis. Raised pavement markers are expected to provide more effective delineation and guidance than conventional striping at night due to their reflective properties. However, raised pavement markers are not expected to be superior to conventional striping in daylight. Daylight was thus used as a comparison condition for the analysis. By considering accident reductions (or increases) at night relative to those during the day, the effects of any changes at the sites between the before and after periods brought about by factors other than the installation of RPM's could hopefully be minimized.

To test statistically for significant reductions or increases in nighttime accident frequencies at each of the 87 locations where raised pavement markers were installed, a statistical procedure based on the cross-product-ratio was used. This procedure is fully described in Griffin (1982). Essentially, the test is based on the following statistic:

$$Z = \frac{\ell n(T)}{\sqrt{1/X_{11} + 1/X_{12} + 1/X_{21} + 1/X_{22}}}$$

where:

Z is a standard normal variate with a mean of 0 and a variance of 1,

ℓn is the natural logarithm,

T is a cross product ratio of accidents at night relative to day, calculated as:

$$T = \frac{X_{11}\ X_{22}}{X_{12}\ X_{21}}$$

and

X_{11} = accidents occurring in daylight in the before period,
X_{12} = accidents occurring in darkness in the before period,
X_{21} = accidents occurring in daylight in the after period,
X_{22} = accidents occurring in darkness in the after period,

A positive value of Z indicates an increase in nighttime accidents from the before to the after period relative to daytime accidents. A negative Z value indicates a decrease in nighttime accidents from the before to the after period relative to daytime accidents. A zero value of Z indicates no change in nighttime accidents from the before to the after period relative to daytime accidents.

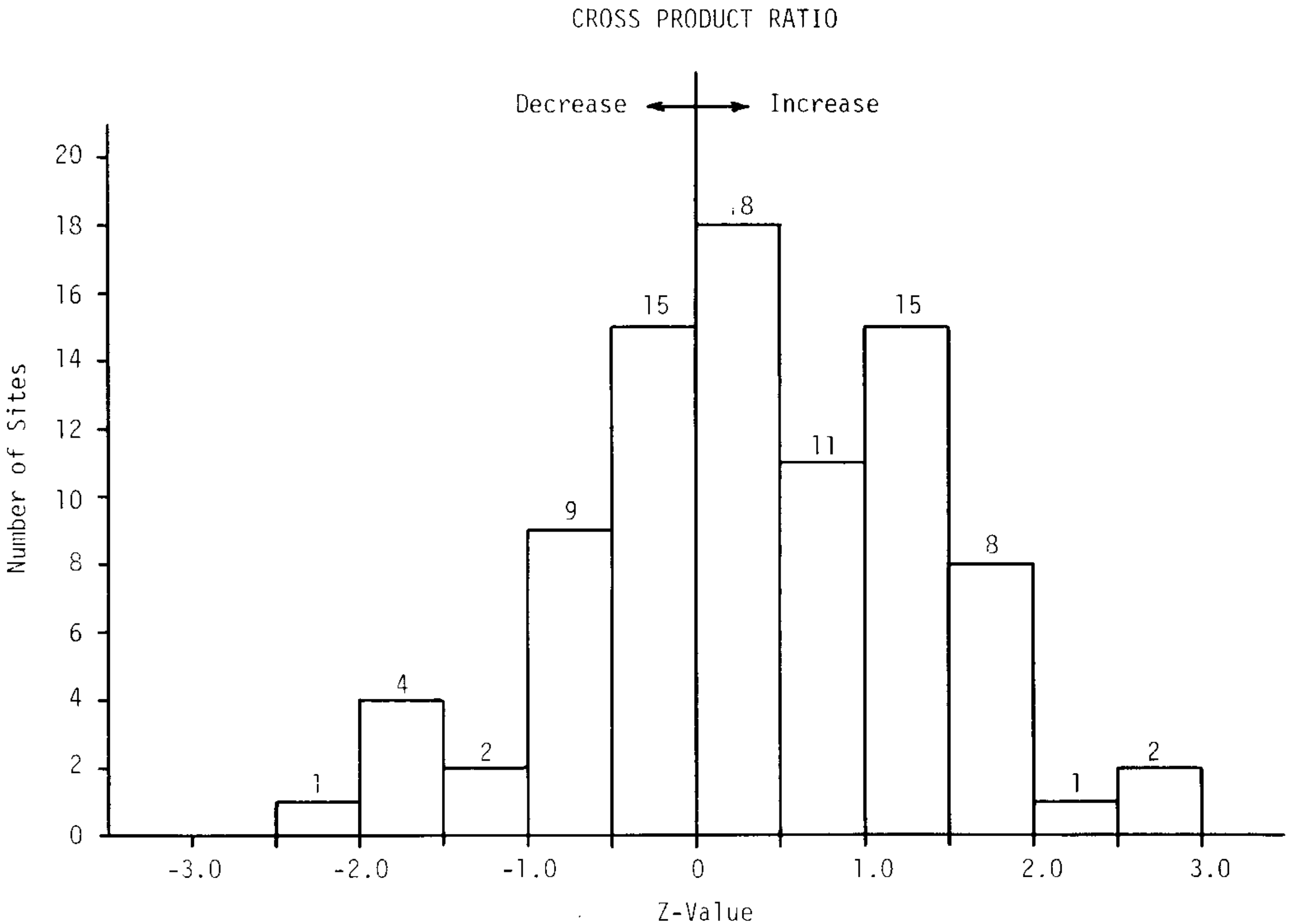
The results of the cross-product-ratio tests for the 87 locations indicated that 56 (64.4%) locations yielded positive Z values, 30 (34.5%) locations showed negative Z values, and 1 (1.1%) location measured zero. With a confidence level of 10 percent ($\alpha = 0.10$), the following results were found:

1. Four (4.6%) locations showed significant reductions in nighttime accidents from the before to the after period when daytime accidents were used as a comparison.
2. Nine (10.3%) locations showed significant increases in nighttime accidents from the before to the after period when daytime accidents were used as a comparison.
3. Seventy-four (85.1%) locations showed non-significant reductions or increases in nighttime accidents from the before to the after period when daytime accidents were used as a comparison.

The results just described are shown graphically in Figure 2. Descriptions of the four locations that showed significant reductions in nighttime accidents, and the nine locations that showed significant increases in nighttime accidents are presented in the Appendix.

<u>Effect of RPM's on Accident Severity</u>

Accident severity at the 101 RPM study locations was examined and the distributions tabulated by nighttime/daytime and before/after, as shown in Table 1. The table indicates that there were slight increases in the proportions of incapacitating-injury (A), non-incapacitating-injury (B), and possible-injury (C) accidents, from the before to the after period during nighttime and daytime.



*NOTE: There is 1 site with
no change (Z=0)

Figure 2. Distribution of Cross Product Ratio by Location.

Table 1. Accident Severity for 101 Sites (Percent)

Accident Severity	Nighttime		Daytime	
	Before	After	Before	After
Fatal (K)	2.90	2.80	1.30	0.90
Incapacitating Injury (A)	7.50	9.40	4.30	4.80
Non-Incapacitating Injury (B)	14.80	17.50	10.70	12.19
Possible Injury (C)	8.50	9.70	8.40	9.64
Property Damage Only (O)	66.30	60.60	75.30	72.50
Total	100.00	100.00	100.00	100.00
N	1,321	1,488	3,343	3,289

In order to examine accident severity statistically at the location level, only locations with sufficiently large numbers of accidents were retained for the analysis. Locations with a minimum of 30 accidents in the before or the after period, or locations with a minimum of 60 accidents in the two periods combined were deemed appropriate for this analysis. Only 37 out of the 101 locations were found to meet either or both of these sample-size criteria and were included in further statistical analyses.

In order to assess the overall severity pattern at the location level, two different severity indices, representing two different levels of severity were defined for each site:

S_1 = (Percent of fatal or incapacitating-injury accidents in after period) - (Percent of similar accidents in before period), i.e., $\%\,(K+A)_{\text{After}} - \%\,(K+A)_{\text{Before}}$

S_2 = (Percent of fatal, incapacitating-injury, or non-incapacitating-injury accidents in after period) - (Percent of similar accidents in before period, i.e., $\%\,(K+A+B)_{\text{After}} - \%\,(K+A+B)_{\text{Before}}$

The values of S_1 and S_2 were obtained for each of the 37 sites, separately for darkness and for daylight. A positive value of S_1 indicates an increase in the percentage of severe accidents while a negative value of S_1 indicates a decrease in the percentages of severe accidents from the before to the after period. The same could be said about a positive and a negative value of S_2, except for the different severity levels.

Figures 3A and 3B show plots of the S_1 values separately for darkness and for daylight, respectively. Figures 4A and 4B show plots of the S_2 values for darkness and for daylight, respectively. Both sets of figures indicate that the change in the overall severity at night for the 37 sites after the RPM installation was relatively small, though slightly greater than the increase in severity for daytime accidents.

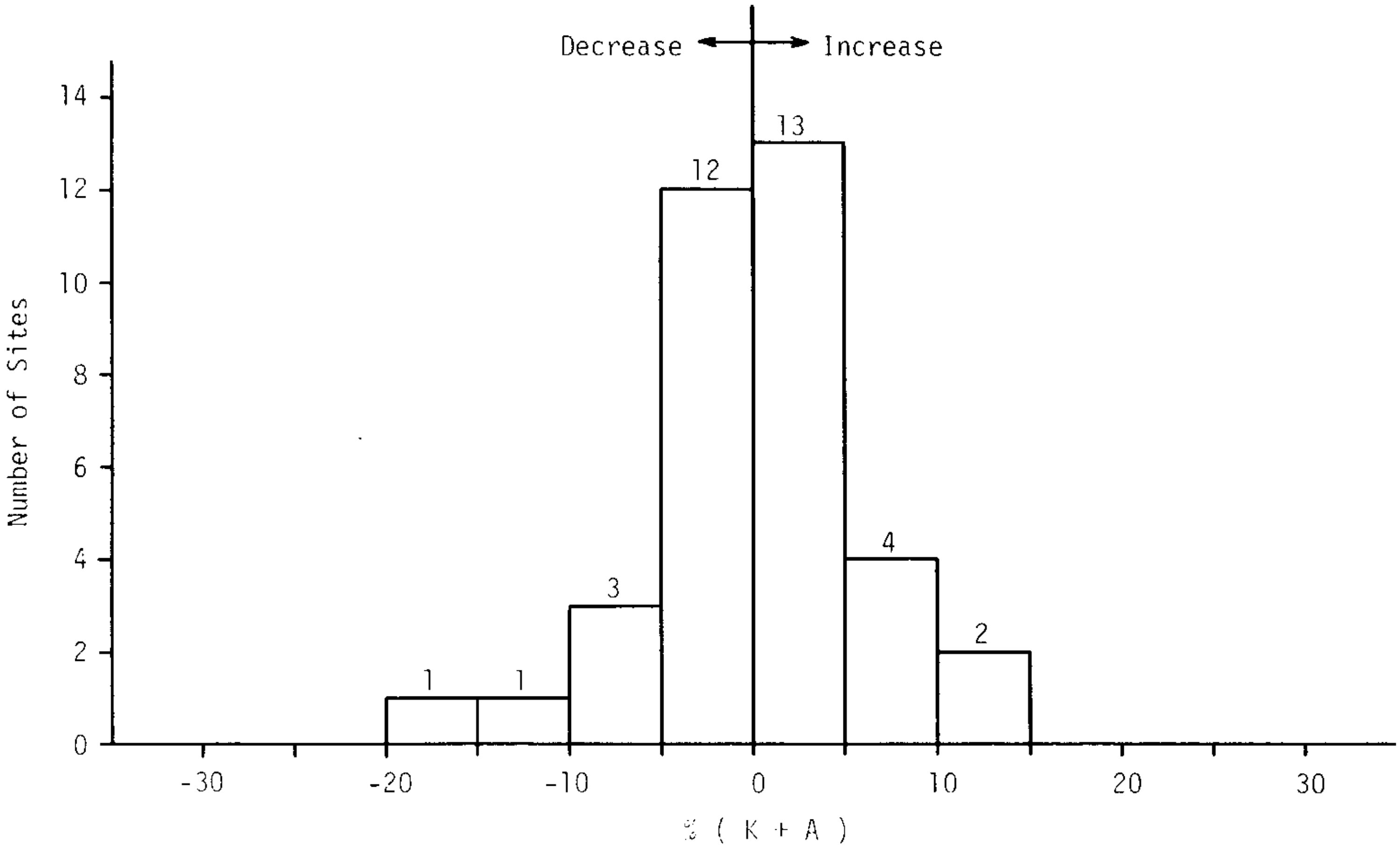
Accident severity at the 37 individual locations was next statistically evaluated. The statistical tests of accident severity involved determining the change in accident severity from the before to the after period during hours of darkness when compared to that during daytime. Of particular interest were decreases or increase in the following probabilities:

(a) probability of severe accidents - defined as the proportion of total accidents that were fatal or incapacitating-injury, i.e., % (K+A) accidents and

(b) probability of injury accidents - defined as the proportion of total accidents that were fatal, incapacitating-injury, or non-incapacitating-injury, i.e., % (K+A+B) accidents.

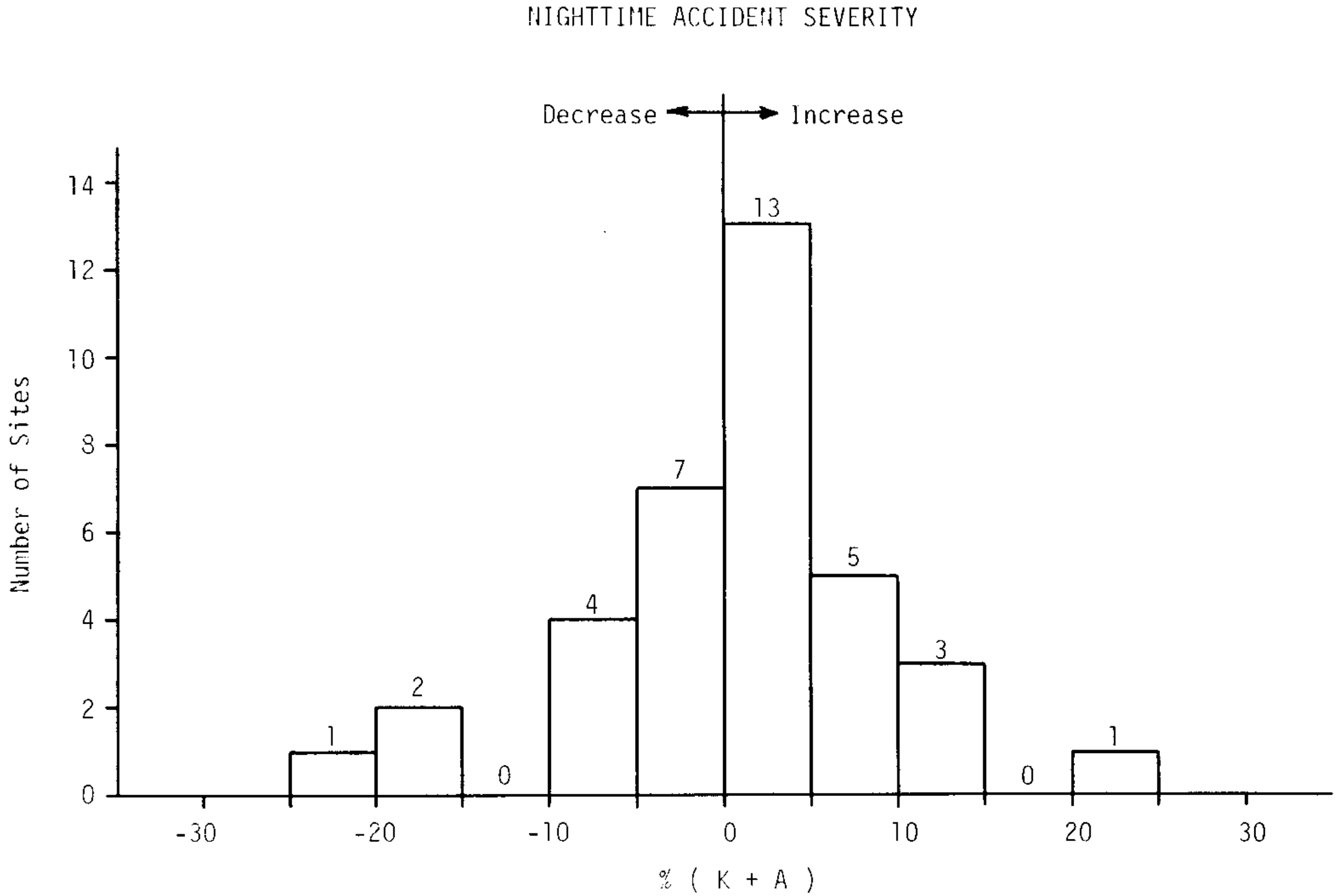
The statistical procedure used to test these two probabilities was a logit model. Of the 37 locations tested, none showed statistically significant results for the probability of severe (K+A) accidents. This finding was probably due, at least in part, to the very small number of severe accidents at each site. For the probability of injury (K+A+B) accidents, five locations showed statistically significant changes in severity after RPM installation. Note that none of these five locations showed statistically significant changes in accident frequency, i.e., none of these five locations are included in Appendix A. Four of these five locations showed significant decreases in the severity of nighttime accidents relative to daytime accidents after the RPM installation. One

DAYTIME ACCIDENT SEVERITY



*NOTE: There is one site with no change (0)

Figure 3A. Distribution of Daytime Accident Severity (K+A) by Location



*NOTE: There is one site with no change (0)

Figure 3B. Distribution of Nighttime Accident Severity (K+A) by Location

DAYTIME ACCIDENT SEVERITY

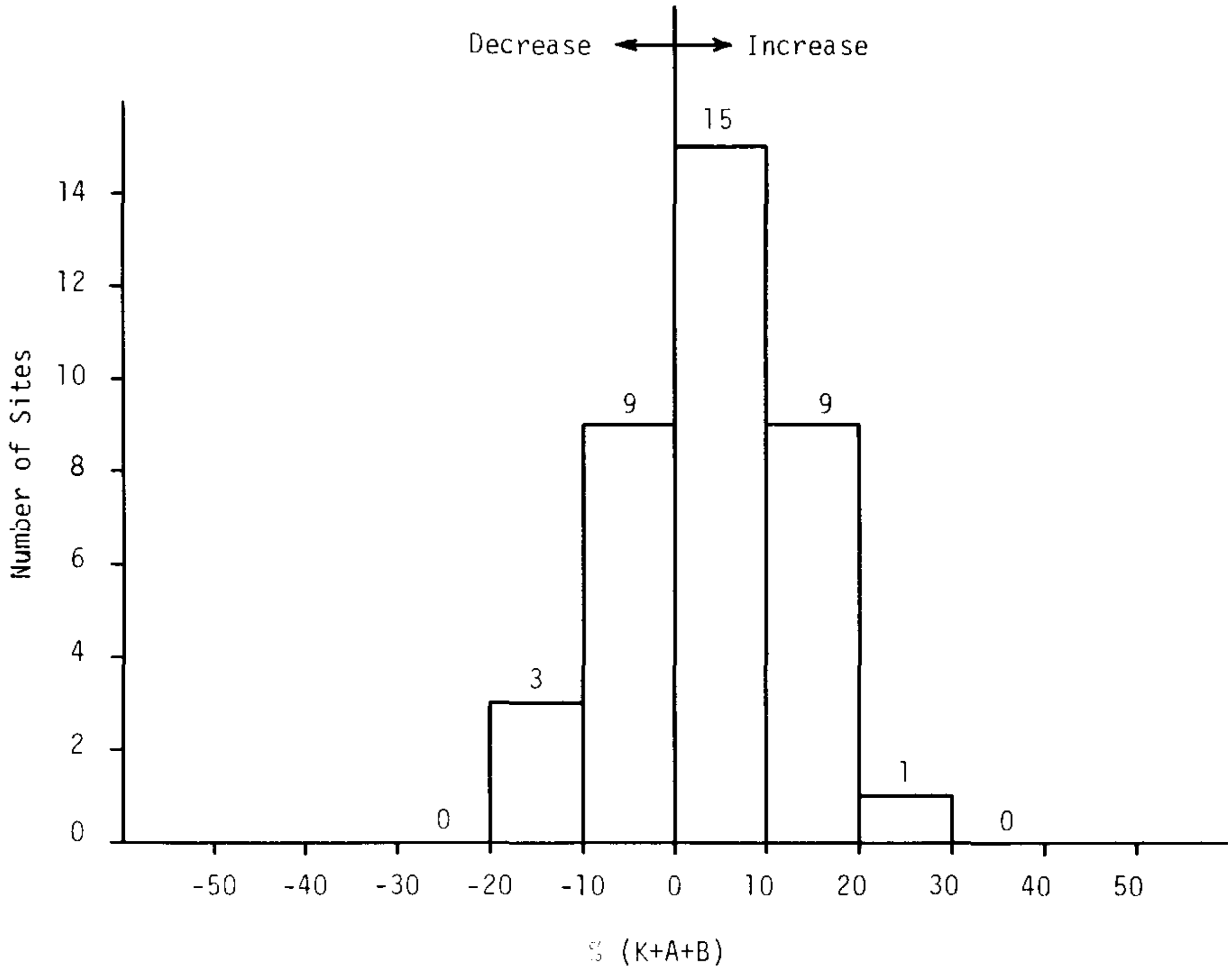


Figure 4A. Distribution of Daytime Accident Severity (K+A+B) by Location

NIGHTTIME ACCIDENT SEVERITY

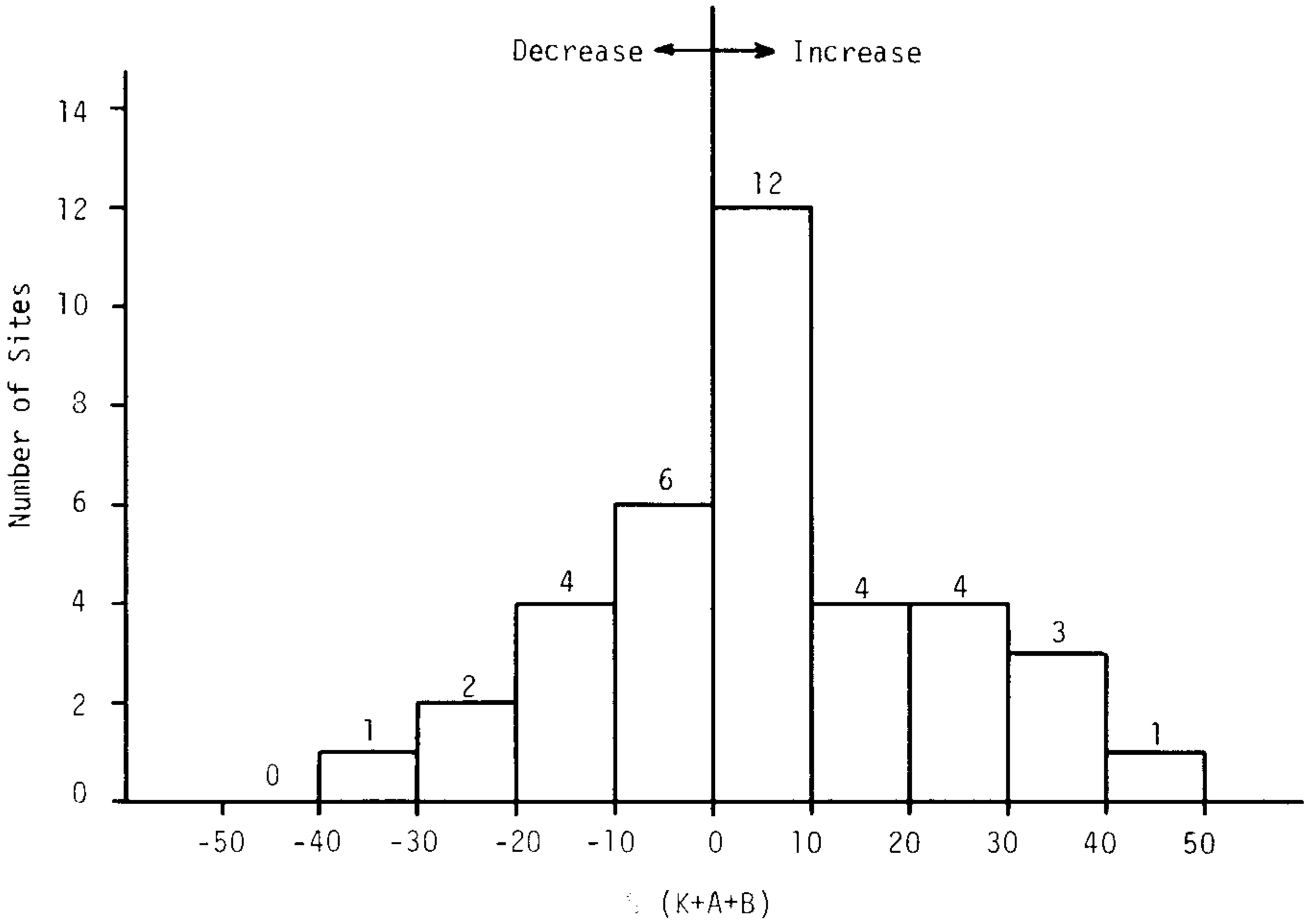


Figure 4B. Distribution of Nighttime Accident Severity (K+A+B) by Location

location showed a significant increase in the severity of nighttime accidents relative to daytime accidents after the RPM installation.

Another comparison of changes in accident severity associated with the installation of RPM's was performed. This analysis compared the nine locations with significant increases in nighttime accident frequencies to the four locations that showed significant decreases in nighttime accident frequencies. Tables 2 and 3 indicate that, for the nine accident-increasing locations, the percentages of nighttime fatal, incapacitating-injury, non-incapacitating-injury, and possible-injury accidents, increased dramatically after RPM installation, much more so than during hours of daylight. For the four accident-decreasing locations, accident severity increased after the RPM installation for both nighttime and daytime accidents, but especially daytime accidents.

Table 2. Accident Severity for the Nine Accident-Increasing Locations (Percent).

Accident Severity	Nighttime		Daytime	
	Before	After	Before	After
Fatal (K)	0.0	5.1	2.7	1.8
Incapacitating-Injury (A)	4.8	9.0	7.1	9.8
Non-Incapacitating Injury (B)	8.3	18.6	9.8	10.3
Possible Injury (C)	2.4	12.8	8.3	9.4
Property Damage Only (O)	84.5	54.5	72.0	68.8
Total	100.0	100.0	100.0	100.0
N	84	156	336	224

Table 3. Accident Severity for the four Accident-Decreasing Locations (Percent).

Accident Severity	Nighttime		Daytime	
	Before	After	Before	After
Fatal	5.1	6.5	1.7	0.0
Incapacitating-Injury	11.9	12.9	3.4	11.2
Non-Incapacitating Injury	18.6	22.6	13.8	21.4
Possible Injury	5.1	6.5	12.1	10.2
Property Damage Only	59.3	51.6	69.0	57.1
Total	100.0	100.0	100.0	100.0
N	59	31	58	98

Accident Characteristics of RPM Locations

In the two previous sections, it has been shown that some of the 101 highway locations considered in this study were associated with increases in accidents and accident severity at night following installation of RPM's. In this section, an attempt is made to characterize the kinds and types of accidents that occurred at the 101 study locations during nighttime and daytime, before and after the installation of RPM's. Table 4 shows that, for the different accident characteristics considered, there was relatively little change from the before periods to the after periods for either nighttime accidents or daytime accidents. Of the variables considered, the one subject to the greatest change appears to be "intersection related." For nighttime accidents, the percentages of accidents classified as "intersection related" increased from 28.3 percent to 33.0 percent from the before to the after period.

The various accident characteristics were next examined by groups of sites. The nine locations that showed increases in nighttime accidents from the before to the after period relative to daytime accidents were grouped together as accident-increasing locations. The four sites which had shown statistically significant reductions in nighttime accidents from the before to the after period relative to daytime accidents were similarly grouped as accident-decreasing locations. It was hoped that by evaluating only those locations that showed significant changes in

Table 4. Accident Distribution on Selected Characteristics by Nighttime/Daytime and Before/After

	Nighttime		Daytime	
	Before	After	Before	After
First Harmful Event (%)				
Overturn or other single-vehicle	9.2	8.9	5.6	4.4
Fixed-object	26.9	27.8	9.7	9.6
Multiple-vehicle	49.6	51.2	80.6	82.7
Other	14.4	12.1	4.1	3.1
Manner of Collision (%)				
Angle	12.3	14.4	23.0	23.4
Same direction	23.9	24.8	41.2	41.6
Opposite direction	12.5	12.0	14.2	16.6
Other	51.3	48.8	21.6	18.4
Accident Factor (%)				
Loss of control	1.7	3.0	1.4	2.2
Lane changing	2.1	2.2	3.5	3.0
Driveway related	7.5	7.5	13.7	13.7
Other	88.7	87.3	81.4	81.1
Number of Vehicles Involved (%)				
1	47.0	44.8	16.6	14.6
2	49.7	52.7	78.5	79.3
3	2.8	2.2	4.3	5.6
4+	0.5	0.3	0.6	0.5
Weather/Road Surface Condition (%)				
Adverse	20.6	21.2	20.8	21.3
Non-adverse	79.4	78.8	79.2	78.7
Roadway Related (%)				
On roadway	65.0	63.0	84.4	85.5
On shoulder	19.4	18.1	9.3	8.1
Beyond shoulder	15.6	18.9	6.3	6.5
Degree of Curvature (%)				
Straight	85.1	81.8	89.4	87.8
< 2 degrees	5.1	7.7	4.5	5.7
2 - 4 degrees	5.2	5.7	3.6	4.1
> 4 degrees	4.6	4.8	2.5	2.4
Intersection Related? (%)				
Yes	28.3	33.0	51.3	51.1
No	71.7	67.0	48.7	48.9
Number of Lanes of Roadway (%)				
2	75.7	79.6	70.6	74.9
4	24.3	20.4	29.4	25.1
N	1,321	1,488	3,343	3,289

accident frequency the likelihood of detecting concrete evidence of changes in certain accident characteristics after the RPM installations would be improved.

The nine locations showing statistically significant increases in accident frequencies and the four locations showing statistically significant decreases in accident frequencies were examined in detail. This analysis was aimed at identifying and comparing changes in the distributions of selected accident characteristics after the RPM installations between the nine accident-increasing locations and the four accident-decreasing sites so that the extent of the RPM's influence, if any, might be identified.

Of the various accident variables examined, only three variables showed differences in their distributions between the before and the after periods that were sufficiently large to be of interest. These three variables, which are depicted in Tables 5 through 10, were first harmful event, degree of curvature, and weather/surface condition.

The nine accident-increasing locations combined showed an increase in the proportion of multiple-vehicle accidents in the after period for darkness (52 percent in the after period compared to 39 percent in the before period). These nine locations also showed a considerable reduction in the proportion of fixed-object accidents in the after period for darkness (28 percent in the after period compared to 43 percent in the before period). Proportions of other single-vehicle and other accidents did not change from the before to the after period. These trends also held true when the nine locations were examined individually. In daylight, the proportions of all accident types were similar between the after and the before periods. The distribution of first harmful events by daytime/nighttime and before/after is shown in Table 5 for these nine locations combined.

Table 5. Percent of First Harmful Event for the Nine Accident-Increasing Locations

First Harmful Event	Nighttime Before	Nighttime After	Daytime Before	Daytime After
Multiple-Vehicle	39.3	51.9	78.3	77.7
Fixed-Object	42.9	28.2	11.6	11.6
Other Single-Vehicle	10.7	10.9	8.3	8.5
Other	7.1	9.0	1.8	2.2
Total	100.0	100.0	100.0	100.0
N	84	156	336	224

For the four accident-decreasing sites, there was little change in the proportions of accident types in darkness between the after and the before periods. A slight increase in the proportion of multiple-vehicle accidents and a reduction in the proportion of fixed object accidents, were observed for daylight. Table 6 shows the distribution of first harmful events for the four sites combined by daylight/darkness and before/after.

Table 6. Percent of First Harmful Event for the Four Accident-Decreasing Locations

First Harmful Event	Nighttime Before	Nighttime After	Daytime Before	Daytime After
Multiple-Vehicle	40.7	41.9	72.4	80.6
Fixed-Object	20.3	22.6	12.1	6.1
Other Single-Vehicle	15.3	12.9	10.3	8.2
Other	23.7	22.6	5.2	5.1
Total	100.0	100.0	100.0	100.0
N	59	31	58	98

The explanation for the nine accident-increasing locations showing a higher number of multiple-vehicle accidents than expected, but a lower number of fixed-object accidents than expected, could not be determined from available accident data. It was possible that site-specific elements for these nine locations as well as interactions among various factors might have contributed to this phenomenon. Unfortunately, the small sample of accidents did not permit meaningful multivariate analysis to be conducted to account for some of these interactions.

Tables 7 and 8 show the distributions of accidents by degree of curvature, nighttime/daytime, and before/after, for the nine accident-increasing locations and the four accident-decreasing locations, respectively. It can be seen that for both groups of locations, the proportions of accidents on curves greater than 2 degrees were higher in the after period for darkness, but relatively unchanged for daylight. Based on Tables 7 and 8 alone, it might appear that after the RPM installation the percentage of nighttime accidents on curves could be expected to rise. However, this same trend was not seen in Table 4 when all 101 locations were collectively examined. It is also noted that the results from Tables 7 and 8 were based on relatively small samples, particularly for accidents on curves greater than 2 degrees.

Tables 9 and 10 show the distributions of accidents by weather/surface condition, daytime/nighttime, and before/after, for the nine accident-increasing locations and the four accident-decreasing locations, respectively. Weather/surface condition is a composite of two variables - weather condition and surface condition. The weather/surface condition is defined as: non-adverse if the weather is clear or cloudy and the surface is dry; and adverse if either the weather or the surface condition is adverse.

It can be seen that, for the four accident-decreasing locations, there was a reduction of adverse-condition accidents in darkness in the after period (from 24 percent in the before period to seven percent in the after period). Such a reduction was also found for the four locations individually. In daylight, there was a slight increase in adverse-condition accidents (from 17 percent in the before period to 23 percent in the after period) for the four locations combined.

For the nine accident-increasing locations combined, there was little difference in the proportion of adverse-condition accidents between the before and after periods, for either darkness or daylight. Examination of the nine locations individually revealed that, in darkness, six locations showed no changes, one location showed an increase, and two showed reductions, in the proportion of adverse-condition accidents in the after period. This random trend among the nine locations also applied for daylight.

The trend indicated in Table 10, for accident-decreasing sites, was based on extremely small numbers of adverse-condition accidents for darkness, and thus might not be stable. In fact, when additional analysis of individual locations was conducted, it appeared that there was a great deal of random fluctuation in the distribution of accidents by weather/surface conditions, which cast considerable doubt on the validity of the tenuous trend indicated in Table 10.

Table 7. Accidents by Degree of Curvature for the Nine Accident-Increasing Locations

Degree of Curvature	Nighttime		Daytime	
	Before	After	Before	After
Straight	86.3	80.8	86.1	82.6
< 2 degrees	9.6	7.0	7.4	10.3
2 - degrees	2.7	7.1	1.5	3.1
> 4 degrees	1.4	5.2	5.1	4.0
Total	100.0	100.0	100.0	100.0
N	73	156	258	224

Table 8. Accidents by Degree of Curvature for the Four Accidents-Decreasing Locations

Degree of Curvature	Nighttime		Daytime	
	Before	After	Before	After
Straight	86.3	80.6	76.6	79.4
< 2 degrees	3.9	0.0	4.3	3.1
2 - 4 degrees	9.8	16.1	19.1	16.5
> 4 degrees	0.0	3.2	0.0	1.0
Total	100.0	100.0	100.0	100.0
N	51	31	47	97

Table 9. Weather/Road Surface Conditions for the Nine Accident-Increasing Locations

Weather Surface Conditions	Nighttime		Daytime	
	Before	After	Before	After
Adverse	25.0	24.4	22.9	25.4
Non-Adverse	75.0	75.6	77.1	74.6
Total	100.0	100.0	100.0	100.0
N	84	156	336	224

Table 10. Weather/Road Surface Conditions for the Four Accident-Decreasing Locations

Weather Surface Conditions	Nighttime		Daytime	
	Before	After	Before	After
Adverse	23.7	6.5	17.2	22.5
Non-Adverse	76.3	93.5	82.8	77.6
Total	100.0	100.0	100.0	100.0
N	59	31	58	98

Roadway Characteristics of RPM Locations

As described under the Study Approach in Chapter II, seven selected roadway characteristics were manually coded from the roadway inventory file (RI-1-LOG) in an effort to identify roadway characteristics that may affect the influence of RPM's on accident frequency and severity. Due to the time and funding constraints for the study, only the nine locations showing drastically significant increases in accidents and the four locations showing drastically significant reductions in accidents were included in this supplemental analysis.

Distributions of accidents by these seven site variables were examined location by location as well as by groups of locations (increasing or decreasing locations). Comparisons of the accident distributions by each variable between the before and the after periods for darkness and for daylight are shown in Tables 11 and 12.

Table 11. Accident Distribution on Selected Roadway Characteristics by Nighttime/Daytime and Before/After for the Nine Accident-Increasing Locations

	Nighttime		Daytime	
	Before	After	Before	After
Types of Intersection (%)				
None	63.1	58.4	54.0	45.0
Interchange	4.8	1.9	5.5	8.2
T-intersection	3.6	5.8	4.0	4.5
4-leg intersection	15.4	13.6	21.6	21.4
Multiple intersection	13.1	20.1	14.9	20.9
Urbanization (%)				
Outside city limit	46.4	48.7	27.7	32.3
Within city limit	53.6	51.3	72.3	67.7
Horizontal Curvature (%)				
Less than 1 degree	86.9	85.1	90.2	84.5
1-3 degrees	10.7	7.8	4.9	8.6
Greater than 3 degree	2.4	7.1	4.9	6.8
Grade (%)				
Less than 3 percent	84.5	90.9	76.2	83.2
Greater than 3 percent	15.5	9.1	23.8	16.8
Structures (%)				
None	88.1	88.3	94.5	91.8
Culvert	7.1	0.6	1.8	1.4
Bridge	4.8	11.0	3.7	6.8
Number of lane (%)				
Less than 4	67.9	76.0	61.6	69.5
Greater than 4	32.1	24.0	38.4	30.5
Divided/Undivided (%)				
Undivided	76.2	72.7	63.1	62.3
Divided	23.8	27.3	36.9	37.7
N	84	154	328	220

Table 12. Accident Distribution on Selected Roadway Characteristics by Nighttime/Daytime and Before/After for the Four Accident-Decreasing Locations

	Nighttime		Daytime	
	Before	After	Before	After
Types of Intersection (%)				
None	66.1	64.5	55.2	49.0
Interchange	6.8	3.2	0.0	2.0
T-intersection	18.6	19.4	24.1	25.5
4-leg intersection	6.8	9.7	19.0	18.4
Multiple intersection	1.9	3.2	1.7	5.1
Urbanization (%)				
Outside city limit	55.9	58.1	34.5	29.6
Within city limit	44.1	41.9	65.5	70.4
Horizontal Curvature (%)				
Less than 1 degree	78.0	67.7	72.4	63.3
1-3 degrees	18.6	25.8	27.6	24.5
Greater than 3 degree	3.4	6.5	0.0	12.2
Grade (%)				
Less than 3 percent	100.0	100.0	94.8	100.0
Greater than 3 percent	0.0	0.0	5.2	0.0
Structures (%)				
None	84.7	93.5	79.3	76.5
Culvert	15.3	6.5	19.0	20.4
Bridge	0.0	0.0	1.7	3.1
Number of lane (%)				
Less than 4	64.4	74.2	100.0	89.8
Greater than 4	35.6	25.8	0.0	10.2
Divided/Undivided (%)				
Undivided	66.1	77.4	96.6	98.0
Divided	33.9	22.6	3.4	2.0
N	84	154	328	220

The examination of these seven selected roadway characteristics did not yield any strong evidence that any of these characteristics interacted with RPM installation to increase or reduce nighttime accidents. Some tenuous indications of accident reductions or increases were seen for some individual locations. However, no consistent patterns emerged for other locations, which in turn indicated that these tenuous trends might be the result of the randomness of accidents, and/or that other factors were at play.

Finally, a clinical evaluation was conducted by examining the accident frequency and the selected roadway characteristics for each of the 0.1 milepoints within the selected locations in an attempt to identify any trends that may help to explain the observed effect of RPM installations. It was noted that accidents tended to concentrate at interchanges and intersections and changes in accident frequencies were usually observed at these sites. Accidents on basic highway segments, i.e., non-intersection locations, tended to be very sparse and spread out with no identifiable trends. There were also weak trends showing that accidents tended to increase at curves with curvature greater than three degrees and at bridges, but the numbers of accidents at these sites were too scattered to provide any definitive conclusions. More details on the results of this clinical evaluation on individual locations are presented in the Appendix.

CHAPTER IV. DISCUSSIONS AND CONCLUSIONS

Discussions

Much of the analysis effort was devoted to the identification of accident and/or roadway characteristics that might have contributed to the observed negative effects of RPM's. The basic premise is that there may be some accident and/or roadway characteristics that interacted with the RPM's to produce the observed adverse effects. If such characteristics can be identified, it may then be possible to develop some guidelines as to where and how RPM's should be applied in order to minimize any adverse safety effects due to the installation of RPM's.

It was therefore somewhat disappointing that the analysis failed to provide any conclusive answers. There were a few isolated trends identified, but nothing of major significance. There are a number of reasons that may have contributed to this lack of definitive findings and are thus discussed below.

There were no apparent criteria under which locations where selected for installation of RPM's. In other words, the RPM locations were not selected for any specific reason, such as high accident history or identified problem with night visibility, but rather in an apparently random manner. It is unknown as to how the initial RPM locations would compare with the general roadway population in the State, i.e., if the RPM locations are representative of the population. The data screening process which eliminated a large proportion of the initial RPM locations complicated the matter further.

This random selection and screening process also resulted in the locations being very heterogeneous. Within each location, particularly those with considerable length, there were wide variations on the roadway, roadside and traffic conditions. This heterogeneity was clearly evident when the nine accident-increasing and the four accident-decreasing locations were evaluated individually, as shown in the Appendix.

This heterogeneity also greatly complicated the analysis due to the large number of unknown factors and their interactions introduced when these heterogeneous locations were combined together for analysis. Thus, a considerable portion of the analysis was devoted to a location-by-location type of analysis. However, since accidents are rare events, some of the locations simply did not have a sufficiently large sample size for detailed analysis.

The study design is retrospective in nature, i.e., only historical data were used with no monitoring or control of the study locations. Even with the rigid screening criteria, there is no guarantee that there had not been other improvements or modifications made to these "clean" locations. It is conceivable that there may have been some extraneous factors or circumstances that happened at these locations which could affect the analysis results. Also, there is no information on the RPM installation, such as the type and pattern of the installed raised pavement markers. Since the RPM's were installed between 1977 and 1979, the data were simply too old to be retrieved reliably. The lack of such information presents major problems in the interpretation of the analysis results.

Daytime accidents were used as the "control" in the analysis since there were no control or comparison locations available. While daytime accidents may intuitively seem to be a good control since RPM's should have little effect in daytime, the date suggested otherwise. It appeared that daytime accidents had considerably different characteristics from nighttime accidents and may not be as good a control as first anticipated.

In addition to these inherent flaws in the study design, it is also believed that there were other factors at play that were not controlled for in the data collection phase, and these factors might have contributed to the observed phenomenon. Finally, it is also possible that accident data might not be sensitive enough to produce conclusive evidence for the intended analyses, due to the lack of detailed accident and roadway related information.

Conclusions

The results of the analysis suggest that raised pavement markers do not reduce nighttime accident frequency or severity, as one may expect intuitively. Actually, the majority of the RPM locations included in the analysis showed increases in nighttime accident frequencies and, to a lesser extent, accident severity, regardless of whether daytime accidents were used as control or not.

Of greater concern is perhaps the finding that roughly 10 percent of the RPM locations showed statistically significant increases in nighttime accident frequencies relative to daytime accident frequencies after RPM's were installed. The severity of accidents at these locations, expressed as the proportion of fatal and injury accidents, was also found to be much higher after RPM's were installed. It may be argued that the considerable improvement in driver guidance and comfort provided by RPM's could well justify their installation, even if there are no safety benefits. However, it would be a matter of grave concern if the use of RPM's could adversely affect safety at certain locations.

Considerable effort was devoted to the identification of accident and/or roadway characteristics that might have contributed to the observed negative effects of RPM's. Unfortunately, the results did not provide any conclusive evidence as to the factors contributing to this detrimental phenomenon for the reasons explained above.

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APPENDIX

DESCRIPTION OF THE 13 SELECTED LOCATIONS

The nine accident-increasing and the four accident-decreasing locations were examined individually in an attempt to identify any roadway characteristics that might have contributed to the observed changes in accident frequencies from the before to the after periods. For every 0.1 milepoint of each location, the accident frequency by before/after and day/night was listed, together with the seven selected roadway characteristics, as described in Chapter II. The data were then examined clinically and the following is a summary of the results for each of the 13 locations.

Accident - Increasing Locations

Site No. 36:

This site is approximately 14 miles long with a large number of intersections and interchanges, especially for the first 2-mile segment which is within city limits. The highway is undivided with the number of lanes varying from 2, 3, to 4 lanes. There is a bridge right at the beginning of the site. Accidents at night were widely scattered throughout the 0.1 mile segments for the entire 14 miles with the exception of the bridge and the first 2-mile segment. There were 4 nighttime accidents at the bridge after the RPM installation compared to none before the RPM installation. Daytime accidents at this bridge were 7 for the before and 5 for the after periods. The first 2-mile segment, which is within city limits with a number of interchanges and 4-leg intersections, showed 2 or 3 accidents at some interchange/intersection locations, but the accidents were scattered on non-intersection segments. Besides the bridge and the first 2-mile segment, one other milepoint showed an increase in nighttime accidents at milepoint 6.0 (a straight 2-lane road) - 4 accidents were reported after the RPM installation compared to none in the before period.

Site No. 88:

This is a short site, about 1.2 miles long, and is inside city limits. It is a 4-lane highway, mostly undivided, but with a 0.2 mile divided section. The site has five 0.1 milepoints with intersections or multiple intersections. Most of the accidents at this site were daytime accidents (87 accidents in the before and 35 accidents in the after periods). The number of nighttime accidents was small (less than 15 in each period) and they were comparable in numbers for the before and the after periods. Daytime accidents were heavily concentrated within those 0.1 mile segments with intersections, and the numbers of daytime accidents at these 0.1 mile segments were far smaller after the RPM installation than before the installation. It was these marked reductions in daytime accidents that resulted in this location showing a statistically significant increase in accident frequency. The three 0.1 milepoints with major accident reductions showed decreases in the number of accidents from 16 to 6, from 22 to 12, and from 36 to 5 accidents. It is unlikely that changes of such magnitudes could be solely attributed to the influence of raised pavement markers.

Site No. 98:

This site is about 17 miles long, straight, and totally outside city limits. It consists of a long stretch of two-lane undivided segment followed by a long stretch of four-lane divided segment, which then converts back to a two-lane undivided segment at the end. There are 6 intersections and 2 bridges within this site. Accidents were widely scattered throughout the 0.1 mile segments for both day and night with no apparent trends.

Site No. 128:

This site is about 6 miles long, 4.5 miles of which is a 2-lane undivided highway outside city limits. The other 1.5 miles is a four-lane undivided highway within city limits with numerous intersections. On the section outside city limits, accidents were very scattered throughout the 0.1 mile segments. The section within the city limits, however, showed accidents concentrated at two intersections, one a 3-leg intersection and the other a 4-leg intersection. It was at these 2 intersections where increased nighttime accidents after the RPM installation were indicated. (A combined total of 7 nighttime accidents after the RPM installation with no accidents before the installation.) More needs to be known about these locations before the influence of raised pavement markers could be deduced.

Site No. 336:

This site is about 4.5 miles long, a straight, two-lane, undivided highway with two intersections. The number of accidents for this site was small (less than 20 accidents in the before or the after periods). The accidents were widely scattered throughout the entire 4.5 miles for both night and day, indicating the randomness in accident occurrence.

Site No. 418:

This site is about 8.7 miles long, 4 miles of which are a straight, two-lane, undivided roadway with no intersections and outside city limits. The other 4.7 miles is within city limits, mostly straight, two-lane, undivided, with 6 intersections. The number of accidents for the site was small and the accidents were widely scattered throughout the entire section, particularly at night.

Site No. 428:

This site is a 2.5 mile long, straight, two-lane undivided highway within city limits. The site is characterized by an interchange, numerous intersections, and short segments between intersections. Accidents were concentrated at intersections that collectively showed an increase in the number of accidents at night, but a slight decline in daytime accidents. Detailed site/accident information for these intersection locations would be needed in order to assess the effect of the raised pavement markers.

Site No. 435:

This site is about 6 miles long, outside city limits, and is a mostly straight two-lane undivided highway. There are one interchange and 3 intersections within this site. With the exception of the interchange and intersections, few accidents were observed, particularly nighttime accidents. At these intersection locations, some increased in nighttime accidents and some decreased in daytime accidents after the RPM installation were indicated. Again, detailed information on these intersections would be required in order to assess the effect of the raised pavement markers.

Site No. 454:

This section is a 2-lane undivided highway, about 9.5 miles long. There is a 0.8 mile segment that is within city limits and characterized by several intersections. Nighttime accidents within this short urban segment were very scattered. Daytime accidents were also scattered with the exception of the beginning 0.1 mile segment, which showed 12 daytime accidents in the before period and none in the after period. This partially contributed to this site being a statistically significant accident-increasing location. The rest of this site is a two-lane undivided highway outside city limits. It is mostly straight with 5 intersections evenly spaced. With the exception of a 3-leg intersection at milepoint 27.6, accidents on this long rural section were widely scattered. At the above mentioned intersection, an increase in nighttime accidents after the RPM installation was indicated (from zero to 5 accidents).

Accident - Decreasing Locations

Site No. 113:

This site is a straight, 2-lane undivided highway that is almost 10 miles long and mostly outside of city limits. There are 3 bridges, all within 0.5 mile of one another. With few exceptions, accidents were highly scattered throughout the 0.1 mile segments for both day and night, but particularly at night.

Site No. 324:

This site is about 8 miles long, 5.5 miles of which is outside city limits. This section is a two-lane, undivided highway that is relatively straight with 5 intersections. The other 2.5 miles is within city limits, but otherwise similar to the section preceding it. The number of nighttime accidents for this site was small and the accidents were very widely scattered throughout the entire section.

Site No. 431:

This site is 3.7 miles long with 0.2 miles of 4-lane divided highway and 3.5 miles of 2-lane undivided highway, all within city limits. One interchange and numerous intersections are present. At the interchange and one intersection, a decrease in nighttime accidents after the RPM installation was indicated from 8 accidents to none. At 4 other intersections, a sharp increase in daytime accidents was observed after the RPM installation (from a total of 18 accidents to 35 accidents). The changes in accident frequencies at these locations significantly contributed to this site being a statistically significant accident-decreasing site. Since the locations where accident reductions or increases took place were intersections, more needed to be known about these intersections in order to assess the role of raised pavement markers at these locations.

Site No. 455:

This site is a 4-lane divided highway, about 11 miles long, mostly straight, and outside city limits. There are 7 intersections within this site. Accidents for both night and day were widely scattered throughout the entire site.

Summary

The above clinical examination of the 13 selected individual locations provided some insight into roadway characteristics and their relationships to accident frequency. Most non-intersection (basic roadway) segments are relatively straight or have curves of less than 3 degrees. Many curve segments of 3 degrees or more are associated with intersections or interchanges. Thus, findings concerning accidents on curves greater than 3 degrees could possibly be artifacts of intersection-related accidents. There is also considerable variation among the locations in terms of urban/rural, number of lanes, and divided/undivided. They all have intersections or interchanges and some urban sections are made up of mostly intersections and short segments between the intersections. Accidents, particularly nighttime accidents, on non-intersection segments tended to be very random and widely scattered through an entire site. Concentrations of accidents were usually observed at interchanges and intersections or on short segments between successive intersections. These roadway and accident characteristics made the before/after evaluations particularly difficult when the design did not control for possible changes in various factors that might have affected accident propensity. This problem was probably worsened by the lack of "control" sites for comparison purposes.

The clinical examination of the 13 individual sites further suggested that, if raised pavement markers indeed altered accident propensity on highways, the accident data available for this study were not sensitive enough to determine how and why accident propensity was altered. This was not surprising given that accidents on basic highway segments tended to be extremely sparse to the point that they appeared to be totally random. Although changes in accident frequencies were observed at many interchanges and intersections, the magnitude of some of these changes was so large that they could not have conceivably been caused by raised pavement markers alone. Furthermore, the lack of "control" sites and monitoring of the study sites rendered it difficult to make definitive conclusions. Accidents at intersections are especially complex and are likely to be affected by a multitude of factors. More detailed information than that available for this study would be required to determine their probable causes.