HSIS

HIGHWAY SAFETY INFORMATION SYSTEM

The Highway Safety Information Systems (HSIS) is a multi-State safety data base that contains accident, roadway inventory, and traffic volume data for a select group of States. The participating States, California, Illinois, Maine, Michigan, Minnesota, North Carolina, Utah, and Washington, were selected based on the quality of their data, the range of data available, and their ability to merge data from the various files. The HSIS is used by FHWA staff, contractors, university researchers, and others to study current highway safety issues, direct research efforts, and evaluate the effectiveness of accident countermeasures.

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SUMMARY REPORT

# Safety Evaluation of Rolled-In Continuous Shoulder Rumble Strips Installed on Freeways

THE 1997 STATISTICS FROM THE FATALITY ANALYSIS REPORTING SYSTEM (FARS) show that 37,280 fatal crashes occurred, with 11,126 of these crashes being coded as single-vehicle run-off-the-road crashes.[1] This significant safety problem is being addressed with continuous shoulder rumble strips (CSRS) and other safety treatments by many highway agencies. CSRS operate as a countermeasure to a class of crashes related to driver inattention. Driver inattention comes in many forms, including distraction, daydreaming/competing thoughts, fatigue/drowsiness, and alcohol/drug impairment. CSRS are continuous bands of raised material or indentations formed or grooved in the shoulders to alert drivers starting to drift off the road. They alert drivers by transmitting sound and vibration through a vehicle. The warnings provided by CSRS give notice to drivers to take corrective action before they run off the roadway.

This study conducted before/after safety evaluations of projects involving the installation of rolled-in CSRS on rural and urban freeways. During resurfacing and shoulder rehabilitation projects, rolled-in CSRS are formed by a roller that leaves grooves during the compaction of the asphalt on the shoulder. In recent years, most CSRS installations have been of the milled type. Field tests conducted by Virginia Department of Transportation[2] for pavement roughness and sound levels on various typical rumble strips found that the milled type was 12.6 times and 3.35 times greater in the pavement roughness index and sound levels, respectively, than the rolled type.

## State Data Bases Used

Highway Safety Information System (HSIS) data from Illinois and California were used. For Illinois, 63 CSRS projects completed between 1990 and 1993 (encompassing 457.4 km of rural and urban freeways) were available for analysis. For California, 28 CSRS projects completed between 1988 and 1993 (encompassing 197.1 km of freeway) were available for analysis. CSRS were installed at all study sites in both directions, on the inside and outside shoulders of the highway, except at nine sites in California where they were only installed in one direction.

## Analysis Methods

This study employed a before/after approach to assess the safety effects of CSRS on single-vehicle run-off-the-road crashes. There are several approaches one can take to conduct before/after evaluations. The two approaches used in this study were the before/after evaluation with yoked comparisons and the before/after evaluation with a comparison group. A third approach (before/after evaluation with an Empirical Bayes analysis) was considered, but not implemented, since there was no selection bias of treatment sites introduced based on accident history.

The primary objective of conducting before/after evaluations is to estimate the safety effect of an improvement. The estimation procedure involves the prediction of what would have been the expected number of accidents in the after period at the treated sites if no improvement had been implemented. The expected number of accidents is then compared to the observed number of accidents in the after period to estimate the safety effect of an improvement. The two evaluation approaches differ in the way they predict what would have been the expected number of accidents in the after period at the treated sites if no improvement had been implemented.

The first analysis approach used (before/after evaluation with yoked comparisons) involves one-to-one matching between treatment sites (e.g., sites treated with CSRS) and comparison sites (e.g., similar sites not treated with CSRS). The comparison site must have undergone no geometric design or traffic control improvements (beyond routine maintenance) during the periods before and after improvements were made to the corresponding treated site. Accident data are obtained for specified periods before and after the improvement was made for each treated site and matched comparison site. This approach assumes that the change in the number of accidents from the before period to after the improvement was made at each treatment site, had it been left unimproved, would have been in the same proportion as at the matching comparison site.

The second evaluation approach used (before/after evaluation with a comparison group) is a variation of the approach just described. However, rather than one-to-one site matching, a suitable comparison group of sites is selected to match the group of treated sites. Preferably, the comparison group should have more sites than the treatment group. Close agreement between the treatment and comparison groups in the monthly or yearly time series of accident frequencies during the period **before** improvement of the treated sites is important. A statistical test (test for comparability) is used to assess the appropriateness of a comparison group.

A final alternative comparison group analysis was also attempted. Here, rather than a comparison group of (different) sites, the comparison group is composed of a subset of crashes at the treatment site—crashes that would not be expected to be affected by the treatment. Again, the pattern of comparison group crashes should be similar to the treatment group crashes in the before period. In this case, multiple-vehicle crashes were chosen as a comparison group for the single-vehicle run-off-the-road crashes since they would not be expected to be significantly affected by the rumble strips. However, since analysis of the Illinois data indicated different patterns between multiple- and single-vehicle crash trends in the before period, this analysis technique was found to be invalid.

## Results

**Illinois Data:** The first analysis of the Illinois data involved yoked comparison sites. Fifty-five of the treatment sites were used in this analysis and were matched with 55 comparison sites. (The remaining eight treatment sites could not be matched with suitable comparison sites.) The second analysis examined single-vehicle run-off-the-road accidents at selected treatment sites (29 projects) with a corresponding large comparison group.

For the yoked-comparison analysis, the frequency of single-vehicle run-off-the-road accidents in the before period for the 55 treatment sites and 55 yoked comparison sites is shown in **table 1**. Accidents during the after period are shown in **table 2**. The rural freeway and urban freeway mileage for the 55 treatment sites and 55 comparison sites is as follows: rural freeways (treatment group)—316.1 km, urban freeways (treatment group)—107.8 km, rural freeways (comparison group)—309.0 km, and urban freeways (comparison group)—80.9 km.

**Figure 1** displays the before-period accidents from **table 1** with the ordinate expressed as the natural logarithmic (In) of accident frequencies. The time series of accidents appear to be in close agreement (i.e., lines are fairly parallel.) Based on visual comparison of the lines in **figure 1** and results from a statistical test, the yoked comparison group was determined to meet the test of comparability and, therefore, was deemed acceptable.

Using a statistical technique defined by Hauer,[3] the safety effect of the CSRS on single-vehicle run-off-the-road accidents can be defined by calculating an "odds ratio." While somewhat complex to describe, this ratio is based on the expected numbers of both comparison and treatment crashes in both the before and after periods and compares the relative change in these crashes from the before to the after period. The odds ratio assumes that the change in accidents from the before to the after period at the CSRS sites, had they been left unimproved, would have been in the same proportion as in the comparison group. In summary, if there is no effect due to the treatment, then the odds ratio would be approximately 1.0. The odds ratio for this data is:

$$(2801)(1833)/(1895)(2288)/(1+1/1895+1/2288)=1.183 \quad (1)$$

Based on this calculation, the average safety effect of CSRS is estimated to be a reduction of single-vehicle run-off-the-road accidents by 18.3 percent. The standard deviation of this estimate of average safety effect is ±6.8 percent. In like fashion, an analysis of the injury crash data only (omitting non-injury crashes) estimates the average safety effect of CSRS installed on rural freeways to be a 13-percent reduction in single-vehicle run-off-the-road injury accidents. The standard deviation of this estimate of average safety effect is ±11.7 percent.

As described above, the second analysis effort involved a before-and-after evaluation with a (non-yoked) comparison group. The challenge was to set up a proper evaluation to allow for the use of a larger comparison group (as measured by the number of accidents)—i.e., to define a comparison group of sites whose accident trend is similar to the trend for the group of treatment sites for the same before period. As one would expect, there was a significant variation in the before time periods across the 63 CSRS projects. This significant variation was due to the fact that the CSRS projects were implemented in different years and had construction periods of various durations. The projects covered four sets of 4-year before intervals: 1987-1990, 1988-1991, 1989-1992, and 1990-1993. In order to have the longest consistent before period for the largest number of treatment sites, a decision was made to use only the treatment sites that had a before period covering 1988-1990. This resulted in 29 treatment sites that could be compared to a comparison group. The chosen comparison group consisted of 11 sites with 8,273 single-vehicle run-off-the-road accidents in this 1988-1990 before period.

Separate analyses were attempted for the urban and rural freeway data. Unfortunately, the urban comparison group did not meet the test for comparability, and no further urban analyses could be conducted. For the rural freeway data, the odds ratio calculated using the treatment and comparison crash frequencies was 1.211. Therefore, the average safety effect of CSRS installed on rural freeways was estimated to be a reduction of single-vehicle run-off-the-road accidents by 21.1 percent. The standard deviation of this estimate of average safety effect was ±10.2 percent. Analysis of only the injury crash data estimated the average safety effect of CSRS installed on rural freeways to be a 7.3-percent reduction in single-vehicle run-off-the-road injury accidents. The standard deviation of this estimate of average safety effect is ±11.7 percent.

The findings for fatigued/drowsy drivers are unclear. The average safety effect of CSRS involving fatigued/drowsy drivers was estimated to be a 23.6-percent increase of single-vehicle run-off-the-road accidents with a standard deviation of ±20.6 percent. This result seems counter-intuitive and it's clearly uncertain given the high standard deviation. Some possible reasons for the increase in single-vehicle run-off-the-road accidents involving fatigued/drowsy drivers after CSRS were installed are:

There may be a reporting bias by police officers to code more drivers in run-off-the-road accidents as being fatigued/drowsy due to the presence of rumble strips. Police officers

| Year(s) | 1987 | 1988 | 1989 | 1990 | 1991 | 1992-93 | Total |
|---|---|---|---|---|---|---|---|
| Treatment | 276 | 644 | 863 | 596 | 310 | 112 | 2801 |
| Comparison | 240 | 515 | 646 | 521 | 259 | 107 | 2288 |

**Table 1.** Before-period accidents for 55 treatment sites and 55 yoked comparison sites.

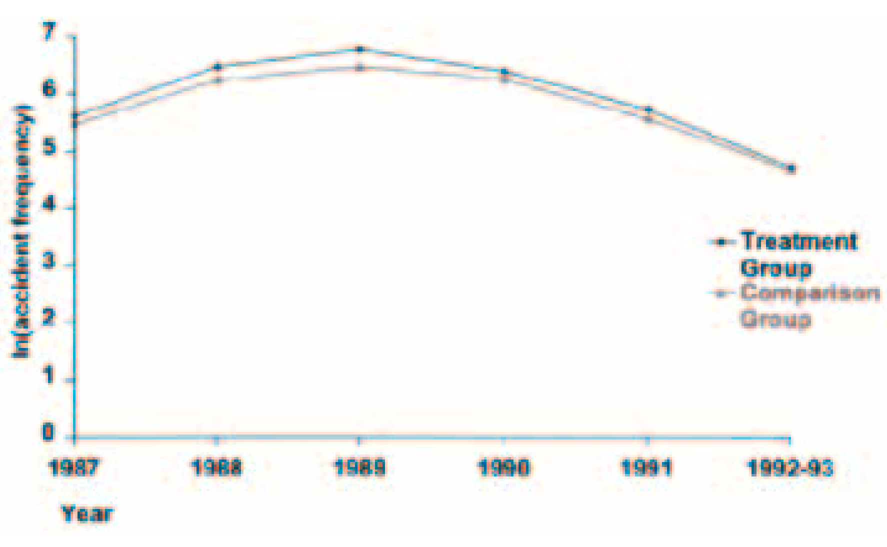


**Figure 1.** Before-period accidents for treatment group and yoked comparison sites.

| Year(s) | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | Total |
|---|---|---|---|---|---|---|---|
| Treatment | 70 | 391 | 500 | 534 | 255 | 145 | 1895 |
| Comparison | 112 | 462 | 460 | 454 | 212 | 133 | 1833 |

**Table 2.** After-period accidents for 55 treatment sites and 55 yoked comparison sites.

may feel more strongly about a driver being fatigued/drowsy since he/she was not alerted out of their "sleepy" condition by the rumble strips in order to prevent the accident.

- There may have been an increase in the number of fatigued/drowsy drivers (increase in exposure) driving through the treated sites (locations where rumble strips exist) from the before to the after period, and this increase may not have occurred at the comparison sites, which could explain the increase in accidents involving fatigued/drowsy drivers. The results are difficult to interpret and there's no way to test the possible explanations given here due to lack of available data. However, as stated above, there was an overall decrease in single-vehicle run-off-the-road accidents after CSRS were installed.

**California Data:** For California, only a limited sample (32.0 km) of urban freeways were treated with CSRS so all of the analyses examined the rural and urban freeway data combined together. The only approach used to evaluate the California data was the before/after evaluation with a comparison group. A total of 17 comparison sites were identified to represent the comparison group for the 28 treatment sites. A larger sample of comparison sites was desirable; however, additional comparison sites deemed suitable couldn't be identified. The odds ratio for the data was calculated to be 1.073, which means the average safety effect of the CSRS was estimated to be a reduction of single-vehicle run-off-the-road accidents by 7.3 percent. The standard deviation of this estimate of average safety effect was $\pm$13.4 percent, which implies a statistically insignificant result.

**Negative Effects of CSRS:** Previous research has alluded to two types of potential adverse effects of CSRS on safety, but no prior research has actually studied these effects. The first type pertains to the possibility that CSRS may cause certain drivers to overreact or panic with regards to the warning, resulting in a loss of control of their vehicles. In an attempt to hold a State liable, some drivers may even claim that a crash occurred because the CSRS caused them to lose control of their vehicle. The second potential adverse effect of CSRS is crash migration. Crash migration occurs when a driver is temporarily saved from a crash by a safety improvement, but crashes downstream along the same highway or at a different point in the network. Study data from Illinois were used to explore the potential of both types of adverse safety effects.

Drivers that panic with regards to the warning provided by CSRS and lose control of their vehicle may get into a single-vehicle or multiple-vehicle accident. Thus, if panic-related single-vehicle accidents were to occur, they should be reflected in the total count of single-vehicle run-off-the-road crashes in the after period of the treatment group. Since, as noted above, the after-period single-vehicle crashes were lower than expected, there is no evidence of a significant "panic" effect on single-vehicle crashes. Even if such an effect exists, it is outweighed by the positive effect of the CSRS.

The possible effect on multiple-vehicle accidents required further examination. Using the Illinois data, the before-and-after histories of multiple-vehicle accidents at the 55 treatment and 55 comparison sites were compared. After the installation of CSRS, a 23-percent decrease in multiple-vehicle accidents was found at the treatment sites and a 23-percent decrease in multiple-vehicle accidents was also found at the comparison sites. Given this result, there's no evidence that CSRS were causing an increase in multiple-vehicle accidents within the boundaries of the treatment area due to driver startle/panic responses. The 23-percent decline in multiple-vehicle accidents at the treatment sites should not be interpreted as the CSRS having a positive effect on this class of accidents since the same percentage of decline was detected at the comparison sites. Based on the available data, it's not clear why multiple-vehicle accidents decreased at the treatment and comparison sites; however, this decrease is consistent with the decrease in overall accidents found at the treatment and comparison sites.

The study of crash migration issues was challenging given the available information. More specifically, studying potential increases in crashes downstream from rumble strip sites was not possible due to data limitations. Many of the CSRS sites were located close to one another (within 40 km [25 mi]), which made the analysis of downstream crashes not sensible since there were very few non-treated sites within a reasonable distance downstream of CSRS sites. However, the Illinois data were explored to assess one aspect of a migration-related problem—the issue of whether CSRS prevented "misbehaving" drivers from running off the road, thus causing them to stay on the road and strike innocent vehicles. "Misbehaving" drivers are drivers that present a significant risk to other drivers and themselves. In this study, they included alcohol-/drug-impaired drivers and fatigued/drowsy drivers. The average safety effect of CSRS for single-vehicle run-off-the-road accidents involving alcohol-/drug-impaired drivers was estimated to be a 36.2-percent reduction.

This group of unsafe drivers temporarily saved by the CSRS may have caused some multiple-vehicle crashes involving harm to innocent victims to occur downstream from a treated site where no CSRS existed. Unfortunately, as noted above, an examination of downstream crashes could not be conducted. However, it was estimated that 47 alcohol-/drug-impaired drivers were saved by the CSRS. It was also estimated that 349 single-vehicle run-off-the-road crashes were prevented by CSRS. The ratio of single-vehicle run-off-the-road crashes saved versus multiple-vehicle crashes possibly caused by alcohol-/drug-impaired drivers was 7.4 (349/47). This is a favorable ratio indicating that if crash migration does exist, then there's no adverse trade-off. As noted earlier, CSRS were not shown to benefit fatigued/drowsy drivers, so crash migration issues were only examined for alcohol-/drug-impaired drivers.

## Study Implications

Sophisticated cost-benefit analyses were not conducted in this study. However, it was estimated that approximately one single-vehicle run-off-the-road accident (at an average cost of $62,200) could be prevented every 3 years based on an investment of $217 to install rolled-in CSRS for 1 km. Clearly, this is a substantial return for a safety treatment that suggests widespread implementation. The current design specifications of the different types of CSRS should be reevaluated given recent concerns raised by bicyclists and operators of emergency and maintenance vehicles. CSRS should be designed to accommodate all highway users, but in a way that maintains their significant safety benefit. Studies of CSRS installed on non-freeways (e.g., two-lane rural roads) should be conducted.

## REFERENCES

1. National Highway Traffic Safety Administration, *Traffic Safety Facts 1996: A Compilation of Motor Vehicle Crash Data From the Fatal Accident Reporting System and the General Estimates System*, August 1997.

2. Chung S. Chen, *A Study of Effectiveness of Various Shoulder Rumble Strips on Highway Safety*, Virginia Department of Transportation, 1994.

3. Ezra Hauer, *Observational Before-After Studies in Road Safety*, Elsevier Science Ltd., 1997.

## FOR MORE INFORMATION

This research was conducted by Michael S. Griffith of the Federal Highway Administration. The final report, *Safety Evaluation of Rolled-In Continuous Shoulder Rumble Strips Installed on Freeways,* will be published by the Transportation Research Board in 2000. For more information regarding the study and HSIS, contact Michael S. Griffith at (202) 493-3316 or mike.griffith@fhwa.dot.gov. FHWA has a web site with information on rumble strips at http://safety.fhwa.dot.gov/rumblestrips.

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