AN EVALUATION OF

SHOULDER RUMBLE STRIPS IN MONTANA

Prepared for:

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RESEARCH SECTION

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An evaluation of shoulder rumble strip's effectiveness in reducing off-road and roll-over crashes on Montana's highway system utilized 10 years of crash data on 393 miles of Interstate Highways and 213 miles of NHS and Primary Highways. Statistical analysis of crash data involved rumble strip segments and control segments without rumble strips for 3 year periods before and after implementation of shoulder rumble strips. Descriptive statistics were developed from global data sets and comparative statistics on equivalent segments produced a finding of significant crash reductions on Interstate Highways, while the affect of shoulder rumble strips on NHS and Primary Highways was uncertain due to an inadequate sample size. Analysis of contingency tables indicate that the reduction in Interstate off-road crash rates attributable to shoulder rumble strips was 14.0% with a corresponding reduction of 23.5% in severity rates. The benefit/cost ratio for construction of shoulder rumble strips on Interstate highways was 19.5.

A shoulder rumble strip driver survey involving questions related to knowledge of rumble strips, frequency of encounters, reaction to exposure, and general opinions on their use was incorporated as part of the study. The survey indicated that 95% of the driving public was familiar with rumble strips and their use with the majority of drivers encountering rumble strips on every highway trip. The overwhelming majority of motorists liked the benefits that shoulder rumble strips provide.</td></tr>
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EXECUTIVE SUMMARY

Purpose

The purpose of this research project was to evaluate the effectiveness of shoulder rumble strips in the prevention of single vehicle off-road crashes on Interstate and primary highways in the state of Montana; to demonstrate the resulting cost-benefit relationship; and to provide information for future policy decisions.

Background

In 1999, MDT formed a research committee to look into the incidence of off-road and rollover crashes. The committee documented the magnitude of the problem, reviewed literature, and made recommendations. It also proposed a research project with the objective of determining shoulder rumble strip effectiveness in reducing the number, severity, and frequency of single vehicle off-road crashes under wet or dry pavement conditions, with an emphasis on rollover crashes specifically.

Methodology

Crash data for three-year periods before and after rumble strip implementation was collected for rumble strip and control segments from the National Highway Interstate System, the National Highway Non-Interstate System, and from State Primary Routes throughout Montana. Descriptive and comparative statistical analyses were performed to quantify the effects of a variety of factors associated with off-road crashes, as well as to gauge the significance of improvement in crash frequencies and severities from before to after periods, for both the rumble strip and control segments of highway. A benefit/cost analysis based upon the reduction of off-road crashes was conducted to evaluate the incentive for further implementation.

Results

It was found that shoulder rumble strips were most effective in reducing the crash rate and severity of off-road and rollover crashes for Interstate highways. Reductions of 14.0% in the crash rate and 23.5% in the severity rate of off-road crashes relative to before and after comparisons between roadways with and without rumble strips were calculated. Reductions in crash rate for the segment of off-road crashes characterized as “roll-overs” were 5.5%, while rollover severity rates increased by a magnitude of 2.7% for Interstate routes.

The limited sample of available data regarding primary routes restricted the investigation of even the broad measures of crash and severity rates. The limited analyses on primary routes indicated that off-road accidents may have benefited from rumble strip implementation, while severity rates for primary routes exhibited an opposite trend for rollover accidents in particular. Benefit/Cost (B/C) ratios on primary routes could not be calculated within any measurable degree of confidence, while the B/C ratio for Interstate routes was calculated to be 19.5.

BACKGROUND

Off-road and rollover accidents have become an increasing concern in the state of Montana and throughout the nation. Many states have recognized shoulder rumble strips as a measure for counter-acting the circumstances, which most often cause these types of accidents.

Definition and Purpose

Rumble strips can be defined as continuous or intermittent bands of raised material or indentations formed or grooved on the pavement surface of a roadway's shoulder or traveled way. The purpose of rumble strips is to alert drivers of an impending vehicular predicament by providing an audible and tactile warning that the drivers' vehicle is either approaching a critical decision point or leaving the roadway. Similar pavement surface texture or audible/vibrational treatments have been in use for nearly fifty years as a means to alert drivers of the possibility of danger. Such treatments have been improved over the years in an effort to develop strip elements that are more effective and can be more easily and accurately installed. This study deals with the performance of shoulder rumbles strips only.

History

Rumble strip experimentation began in 1955 in New Jersey, when 25 miles of the Garden State Parkway were fitted with "Singing Shoulders." (Alexander and Garder, 1995) The use of rumble strip technology continued sparingly on an experimental basis until the mid '80s when, in an April 11, 1986 directive, the United States Department of Transportation (USDOT) endorsed the use of "special shoulder-texture treatments" as an effective measure for improving highway safety. (FHWA, 1986) In Montana, shoulder rumble strips were employed only on an experimental basis prior to 1996. On March 1, 1996, the Montana Department of Transportation (MDT) approved a policy, which incorporated continuous rumble strips on roadway shoulders for all new construction, reconstruction and overlay projects. The policy was then revised on June 23, 2000 to accommodate standards relative to bicycle usage. Substantial lengths of continuous rumble strips were installed on Interstate, NHS, and Primary Highways in Montana beginning in 1995. As of this time, rumble strips border 271.8 miles of Interstate Highway throughout the state. It is not known at this time how many miles of Primary Highway in Montana are protected with rumble strips.

Previous Evaluations

Previous examinations of rumble strip effectiveness completed in various states have produced almost exclusively positive results, although to a varying degree.

In 1976, the Transportation Services Division of what was then called the North Dakota State Highway Department released a report on low cost highway safety improvements, which included a small evaluation of rumble strip performance. Details regarding methodologies were not presented. However, five locations were referenced, and accident rates before and after installation were reported to be 1.351 and 1.029 accidents per million vehicles miles, respectively. That represents a 23.8% decrease in accident rate. It should be noted that the authors felt that findings in the study were biased to a certain degree because of the small sample size. It should also be noted that the rumble strips evaluated were the raised epoxy type.

An evaluation by Cheng, Gonzalez, and Christensen, in 1994, discussed the application of rumble strips on highway shoulders in the state of Utah and appraised their effectiveness from a safety perspective. The intent of the study was to evaluate the difference in accident rates between highway segments with and without rumble strips. Statistical analyses were conducted to compare the accident history of the two groups. Three segments along Interstate 15 were chosen and accident data from the years of 1990 to 1992 was examined for each segment. Overall accident rates and run-off-the-road accident rates were compared. Results showed that accident rates for both accident types were lower on those sections with rumble strips. Highway sections without rumble strips were found to have accident rates 33.4 percent and 26.9 percent higher for overall and run-off-the-road accidents, respectively. Severity of accidents occurring in the study areas was also reviewed. Sections without rumble strips produced accident severity rates (see page 20 for definition) 27.2 percent and 8.7 percent higher for overall and run-off-the road accidents. The results of the study indicated that, as a whole, freeways without shoulder rumble strips experienced a higher rate of accidents than those with shoulder rumble strips. (Cheng, et. Al., 1994)

A study by Wood, also in 1994, considered the effectiveness of the Pennsylvania Turnpike Commission's Sonic Nap Alert Pattern (SNAP) system. Five SNAP projects completed in 1992 were analyzed in May of 1993 to gauge success. Data was extracted for all accidents in which the first object hit was the guardrail or embankment within the milepost limits of the early SNAP installations. At least one continuous year of data was included for each roadway segment, both before and after installation. Results showed a 70 percent reduction in off-road accidents. (Wood, 1994) That figure was later revised to be 65 percent in a follow-up study done by Hickey, Jr. in 1997. The later study reviewed the initial results, added traffic exposure to compare accident rates per vehicle-distance-traveled, and adjusted for a decline in all accidents during the years considered. (Hickey, Jr., 1997)

A 1998 FHWA commentary on the effectiveness of rumble strips in New York State reported a reduction in run-off-the-road (ROR) crashes of at least 65 to70 percent, as reported by the New York State Department of Transportation (NYSDOT) and the New York State Thruway Authority (NYSTA). NYSDOT and NYSTA are the two agencies responsible for rumble strip installation on freeways and toll roads in the state of New York.

A 1999 evaluation completed by Griffith employed a before-after study approach in assessing the safety implications of continuous shoulder rumble strips (CSRS) in the states of Illinois and California. Illinois data was obtained from 63 project sites totaling 457.4 km (284.2 miles) of roadway. All sites were located on urban and rural freeway sections. The first analysis used multi-vehicle accidents as a comparison group. A second analysis involved yoked comparison sites. Results showed that on all freeways, an 18.3 percent reduction in total single-vehicle run-off-the-road accidents was realized through rumble strip implementation, along with a 13.0 percent reduction in injury single-vehicle run-off-the-road accidents. A 21.0 percent reduction in total single-vehicle accidents on rural freeways was also recognized. In California, a total of 28 CSRS projects totaling 197.1 km (122.5 miles) were identified for study, all on rural and urban freeways. Completion dates for the rumble strip projects fell between the years of 1988 and 1993. Nineteen of the sites had rumble strips installed on both sides of each directional roadway, while for the remaining nine, rumble strips were installed in only one direction. Seventeen comparison sites totaling 132.4 km (82.3 miles) were identified for study. All told, 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.

In the state of Montana, a previous evaluation of 13 shoulder rumble strip locations on Interstate and primary highway routes was completed in 1994. The study's locations highlighted a variety of designs and construction methods for rumble strip implementation. Five years of before data, and two years of after data were analyzed, considering the percent change in accident rate for related or "correctable accidents" as a measure of effectiveness. The accident rate for correctable accidents was found to decrease by 3.0 percent for three primary system sites, which had realized a narrowing of shoulders due to pavement overlay. The model predicted that over the same period of time, "uncorrectable accidents" increased by 17.5 percent. Accident rates for sections of primary roadway that had experienced shoulder widening realized a 64.0 percent decrease, while the model predicted a 34.5 percent decrease for related accidents. Primary roadway sections that were widened from two to four lanes in conjunction with rumble strip installation showed a 79.0 percent decrease in accident rate for correctable accidents. No comparative figure was given regarding related accidents. The five Interstate sections examined showed a decrease in average accident rate of 12.0 percent. A "trend in reduction" was mentioned for related Interstate accidents. Overall, the conclusion was made that rumble strips did reduce off-road accidents and it was recommended that such advances should be pursued where bicycle travel was limited. (Jomini, 1994)

Current Study Research Committee

At the outset of this investigation, the MDT Safety Management Section prepared a summary of rollover crashes on Montana highways between 1995 and 1999. It was determined that 22.7 percent of all accidents occurring on the Interstate and State highway systems consisted of rollovers. Rollover accidents were also found to be the most severe, with 20.4 percent of rollover accidents resulting in fatality or incapacitance, as compared to an 11.6 percent average for all crashes. (MDT, 1999) Because of the high incidence and severity of these types of accidents, MDT formed a research committee to investigate their occurrence. The committee assembled all available data and began meeting late in the year 1999. They proposed a research project with the objective of determining the effectiveness of shoulder rumble strips in reducing the frequency and severity of single vehicle off-road crashes, under both wet and dry pavement conditions, with an emphasis on rollover accidents. The committee assembled numerous studies and reports dealing with accidents and rumble strips from a number of states. The reports ranged from detailed statistical analyses to brief statements relative to before and after accident exposure. Research materials indicated potential for accident frequency reduction ranging between 10 and 80 percent. However, hardly any of the reports presented detailed analyses regarding safety effectiveness relative to specific variables, such as shoulder width or bicycle usage. As such, the committee developed a set of research objectives to be evaluated in this study. They are included in the following section of this report. The current research committee is as follows:

<u>Members</u>
Craig Abernathy, Research Section
Pierre Jomini, Safety Management Section

Bill Squires, Road Design Section
Bob Tholt, Consultant Design Section

MONTANA DEPARTMENT OF TRANSPORTATION POLICY

MDT Engineering Division Management Memo number 96-01, dated March 1, 1996, established a policy for the use of rumble strips on highway shoulders. A draft policy was circulated within MDT and throughout the public, and revisions were made based upon consideration to comments on the draft. The policy was established in reaction to concern for run-off-the-road crashes by sleepy or inattentive drivers combined with research completed in Montana and other states, which indicated that the occurrence of these types of crashes could be reduced substantially through the use of shoulder rumble strips. It was also recognized that bicyclists cannot operate on shoulders with rumble strips and it was indicated that shoulders would be swept as needed.

Shoulder rumble strip design directives included the following dimensions:

Concrete:

Construction -	Formed Continuous Corrugation
Width -	300 mm to 400 mm (12" to 16")
Radius -	25 mm (1")
Depth -	25 mm (1")
Spacing -	114 mm (4.5") Centers
Lateral Offset -	1500 mm (6") Outside Edge Line

Asphalt:

Construction -	Milled
Width -	300 mm to 400 mm (12" to 16")
Radius -	300 mm (12")
Depth -	13 mm to 19mm (0.5" to 0.75")
Spacing -	114 mm (4.5") Centers
Lateral Offset -	1500 mm (6") Outside Edge Line

On Interstate Routes, continuous shoulder rumble strips were to be implemented on both left and right shoulders for all new construction, reconstruction, and overlay projects, except for breaks at:

- Exit ramps 30 meters (100’) upstream, to the gore nose
- Entry ramps at the gore nose, upstream to the taper end

On National Highway and Primary Routes within urban or city limits, the application of shoulder rumble strips was to be based on engineering judgment on a case-by-case basis to determine appropriateness. Shoulder rumble strips on National or Primary Highways were to be continuous on both sides of the roadway, including mailbox turnouts, scenic turnouts, and historic markers. Rumble strips were to be discontinued only across the full width of all public and private road approaches. Rumble strips were to be applied to all new construction, reconstruction, and overlay projects on rural, National, and Primary Highways having shoulder widths greater than 1.2 meters (4 feet), except where justification for their exclusion could be documented on the basis of corridor continuity, approach density, bicycle usage, and crash history. On roadways with shoulder widths less than 1.2 meters (4 feet), justification for their use was to be provided. Consideration of rumble strips on these roadways would be made if there were little or no bicycle use and the incidence of run-off-the-road crashes were high.

The shoulder rumble strip policy noted above was revised on June 23, 2000 and is currently in effect within the State of Montana. The current policy reflects input received from the bicycle community and others regarding rumble strips installed on state highways. This policy removed the original statement that shoulders with rumble strips would be swept for bicyclists as a part of maintenance activities. All detailed dimensions of rumble strips outlined in the original policy were retained, with the only exception being that the width was set at 300 mm (12”) instead of allowing variable widths between 300 mm (12”) and 400 mm (16”).

On Interstate Routes, two additional conditions were imposed: 1.) Rumble strips on the right shoulder application were to have an 18.3 m (60’) cycle pattern consisting of a 14.7 m (48’) rumble strip and a 3.6 m (12’) gap. Left shoulder rumble strips were to remain continuous. 2.) Rumble strips were to be discontinued on outside shoulders less than 1.8 m (6’) wide, if guardrail existed or was planned.

These same conditions were made part of National and Primary Route applications. However, one additional section was added to these conditions, which were to be applied on a case-by-case basis where significant bicycle use had been documented or attested to by the MDT District Administrator. The additional section contains the following guidelines:

1. Consider a 100 mm (4”) offset from the shoulder stripe where shoulder width is 1.2 m (4’) or less.
2. Consider traverse rumble strip widths 200 mm (8”) where shoulder width is 1.2 m (4’) or less.

Shoulder rumble strip sections evaluated within this study were those that conform to the first Policy Memo dated March 1, 1996. None of the study’s segments involved rumble strips installed prior to 1995 and all rumble segments in the study complied with the dimensions and details outlined in the first policy memorandum. Earlier rumble strip applications in Montana were experimental in nature and varied in width, depth, lateral placement, and method of application. These segments were excluded from both rumble strip and control segments in the study. Not enough data was available to provide a statistical analysis between the continuous rumble strip standard and the cyclical patterns detailed in the June 23, 2000 policy memorandum. Research on gap cycles (Moeur, 1999) suggests that the 14.7 m (48’) strip with a 3.6 m (12’) gap pattern outlined in the current policy memo would be as effective as the continuous rumble strip section. Thus, it is logical to assume that study crash statistics within this report would also be applicable to current shoulder rumble strip standards.

STUDY OBJECTIVES

The focus of this study was on single vehicle run-off-the-road crashes under dry or wet pavement conditions only. While it has been suggested that shoulder rumble strips could potentially be linked to other types of crashes, the relationship has not been documented by previous research and was considered beyond the scope of this study. It was felt that including crashes for road conditions other than dry or wet would introduce uncontrolled variables into the analysis, since snow pack, ice, mud, gravel, and other roadway conditions could reduce the effectiveness of rumble strips. In addition, the probability of run-off-the-road crashes is increased by the reduction in pavement friction associated with these surface contaminants. Wet roadway conditions also reduce surface friction, but do not minimize the effectiveness of rumble strips and their inclusion in the study database allows comparisons between two controlled roadway variables. Nearly 60 percent of all the accidents in the state of Montana since 1991 occurred under road conditions classified as “wet” or “dry,” according to MDT “Trafficway Accident Summaries” report. The study purpose, given the above noted conditions, is to evaluate the effectiveness of “Shoulder Rumble Strips” in prevention of single vehicle off-road and rollover crashes within the State of Montana. Specific objectives of this study are listed as follows:

1. Quantify the number and occurrence rate of single vehicle off-road crashes and rollover crashes before and after rumble strips were installed on representative sections of both National Highway Interstate, National Highway Non-Interstate, and State Primary Routes in Montana.

2. Quantify the severity and severity rate of single vehicle off-road crashes and rollover crashes before and after rumble strips were installed on representative sections of both National Highway Interstate, National Highway Non-Interstate, and State Primary Routes in Montana.

3. Analyze trends in single vehicle off-road crashes and rollover crashes before and after rumble strips were installed on representative sections of

both Interstate and two-lane, two-way rural highways in Montana.

4. Compare trends in single vehicle off-road crashes and rollover crashes, with similar shoulder widths and inslopes, on representative sections of Interstate and two-lane, two-way rural highways, and on representative sections without rumble strips (control sections).

5. Correlate single vehicle off-road and rollover crashes to roadway segments and determine potential countermeasures.

These study objectives agree with the objectives listed in the original MDT Research Project Statement, with certain exceptions. Specific segments of Interstate and rural highways with known characteristics were selected as representative samples of the entire highway system instead of including the entire system and introducing unknown variables. In addition, a highway user's survey was conducted, which provided information on users': awareness of rumble strips; encounters with and reaction to rumble strip hits; opinions and concerns; and other information considered to be relevant to shoulder rumble strips. Comparisons were made of survey information with general crash statistics, in terms of potential exposure rates and crash avoidance measures.

STUDY PROCEDURES

The study consisted of five major tasks with basic task activities, as described below:

I Project Organization & Data Collection

- A detailed literature review was completed to provide background information for the research effort and to provide a basis of comparison to similar work in other areas of the country.

- A detailed study site selection process involving various methods and individuals was completed. The focus of the process was to provide an unbiased sample of highway segments as large as possible with as few extraneous variables as possible. The selection process is presented in detail within the next section of this report.

II Data Entry & Preliminary Analysis

- The Montana Department of Transportation (MDT) Safety Management Section provided all available crash data on Interstate Routes and select Primary routes. Tabular printouts from the MDT Transportation Information System (TIS) were scanned and converted to Excel spreadsheets. The TIS data was reformatted and non-study route segments were deleted from the database. All crashes that were not classified as single vehicle off-road crashes and those occurring on roads other than wet or dry were also eliminated. Once all single-vehicle off-road crash data contained within the selected study segments were isolated, specific crash information regarding the roadway, driver, vehicle, and crash circumstances was entered into the spreadsheets. Test data was sent to the MDT Information Services Bureau to ensure that it was compatible with MDT systems. Various levels of data reduction and sorting routines were archived to ensure that pertinent data could be retrieved for inclusion if additional information was needed at a later date.

- Annual Average Daily Traffic (AADT) volumes were calculated for each specific study segment using an Excel spreadsheet. AADT calculations referenced the MDT "Traffic By Section" biannual reports from 1990 to 2000. These reports document traffic counts on numerous route segments. AADT within study segments represent the distance-weighted average of all section volumes within defined limits of the study segment. Study segment AADT values were used to calculate crash rates and severity rates.

- After the database was complete, various sorting routines were run to determine preliminary statistical values. A complete review of sorting routine results was completed to determine variables that were evaluated in greater detail.

III Statistical Analysis & Evaluation

- Crash rate and severity calculations were made for all rumble strip and control sections and various forms of statistical analysis were applied. Before and after comparisons were made for: the global population, equivalent length segments, and comparisons using the control group. A Chi square evaluation was performed to determine difference between the rumble strip and control groups and the paired t-test was used to measure significance of disparity between before and after conditions, for both Interstate and rural highway segments.

- Variables associated with the roadway, driver, and vehicle, which appeared to be significant, were evaluated using descriptive statistics.

IV Highway User Survey

- Four rest areas in different geographic locations, three on Interstate highways and one on a non-Interstate highway, were selected as data collection sites. A survey plan was developed along with an inventory questionnaire and approved by the study review team. The survey plan attempted to determine: average motorists' exposure to rumble strips; first encounter reactions; knowledge of purpose and/or existence; opinion of usefulness; and other information. Interview data was entered into an Excel spreadsheet and statistical analysis of the data was completed. This data and summary were presented in a separate report, which is referenced further in this report.

V Final Analysis & Reports

- Final statistical analysis was completed regarding: before and after conditions for rumble strip segments and control segments using global data and equivalent segment data. Significance testing was completed on equivalent segment data and comparative statistics were applied to all variables within the analysis.

- The statistical findings were correlated to study objectives and crash trends were projected with alternative courses of action. A basic benefit/cost analysis was performed for rumble strips on a per-kilometer basis.

- A draft was submitted to the Rollover Technical Committee for review.

- A presentation of the findings will be made to the Research Committee and Preconstruction staff.

- After final draft review comments have been received, a final report will be produced.

STUDY LOCATIONS

Site Selection Process

Initially, highway sections with rumble strips were tabulated based on information compiled in 1996. The tabulations detailed all of the rumble strip sections completed up until that time. The MDT Construction Bureau then provided a list of projects with rumble strips that had been completed through May of 2000. Project specifics regarding route location, reference posts, and construction dates were investigated and a list of potential study segments was developed. This list is detailed in Table A-1 within the Appendix of this report. Table A-1 lists the route, project number, general location, beginning and end date of construction, beginning and end reference post, and approximate project length. For two-lane primary highways, Table A-1 also indicates the type of project, whether it consisted of a reconstruction, resurfacing, or rumble strip only type of construction. All projects which included rumble strips as a part of primary route reconstruction were eliminated from the study to avoid introduction of extraneous variables. The list encompassed 515 miles of Interstate routes and 493 miles of primary routes. It provided the only documented locations of rumble strips within Montana. However, some sections of older style shoulder rumble strips also existed, without documentation being easily accessible.

Control sections were considered necessary to provide statistically valid comparisons on several levels of comparative analysis, and verification of the existence or absence of shoulder rumble strips was required. Several Interstate and primary study routes were checked to determine the existence of documented rumble strips and to locate sections to be used for control. From several hundred miles of validation checks, it was noted that there were several instances of shoulder rumble strips existing on potential control sections, and also instances where rumble strips were missing from sections where they supposedly existed. In order to avoid introducing substantial error into the analysis, it was decided that the entire Interstate system, and those primary highways routes with documented rumble strip construction projects, would be inventoried. The five District Traffic Engineers drove these routes in their entirety and completed an inventory of highway sections with and without shoulder rumble strips. Because these inventories occurred late in 2001 and early in 2002, several more miles of rumble strip sections were found than originally documented due to construction in 2000 and 2001. Rumble strips were observed on 917 miles of Interstate, nearly double the documented section total. A similar condition was evident for primary highway routes. Rather than reestablishing the location database, it was decided to eliminate all undocumented sections of highway with rumble strips from the list of potential control sections. Thus, the number of control section miles available limited the study sample size.

Study Route Segmentation

Once all candidate study locations were verified, a review of specific route characteristics was undertaken to separate those rumble strip and control segments that had similar characteristics. Characteristics used to segregate study segments were: terrain, overall roadway alignment conditions, rural vs. urban location, traffic volumes, and pavement width (two-lane primary routes). The process of matching characteristics of rumble strip and control segments resulted in the elimination of some potential study segments because they were found to be without a suitable match. This was particularly true of the primary highway locations exhibiting variable pavement widths. It was also discovered that many of the rumble strip segments covered the entire length of a specific roadway type, and that matching control segments existed on noncontiguous sections of the route.

A listing of study sites was developed and reviewed by the research committee. Table A-2 in the Appendix of this report represents the listing of those locations. Table A-2 also lists the beginning and ending mileposts and dates for the documented construction periods. The listing includes 393.4 miles of Interstate and 212.8 miles of primary roadways.

Segmentation of the routes to provide valid comparisons between roadways with similar operating characteristics resulted in the same number of study miles for both rumble strip and control segments. However, the rumble strip and control segments were variable in length. It was determined that the data within these segments would be adequate for analysis of descriptive statistics and that the group of 17 Interstate segments and 14 primary highway segments would be considered the “global” database used for the calculation of descriptive statistics. Within this report, the phrase “Global Segments” refers to this database.

Statistical significance testing, however, requires that all segments have equal characteristics. So it was necessary to further refine the selection of study segments by segmenting the global data into equal length segments. Since this process would further erode the number of study route miles, several segmentation routines were run to determine a segment length to be used that would retain the most number of study miles, while still providing a significant number of crashes within each segment. It was determined that the optimum length was four miles and, as a result, all comparative statistics were based on “four-mile” segment data. Within this report, the phrase “Four-mile Segments” refers to this database.

Table 1 is a summary of global and four-mile rumble strip study segments used in the study analysis. It should be noted that a similar number of control segments was included in the study. Global segment analysis was based on a sample size of 62 rumble strip and control segments totaling 606.2 miles of Interstate and primary highway.

Table 1. Rumble Strip Study Segment Summary

Route	Global Segments			Four Mile Segments	
	No. of Segments	Average Length (mi)	Total Length (mi)	No. of Segments	Total Length (mi)
Interstate 15	4	14.0	56.0	12	48.0
Interstate 90	9	9.5	85.7	17	68.0
Interstate 94	4	13.8	55.0	13	52.0
Total Interstate	**17**		**196.7**	**42**	**168.0**
Primary 1	4	7.2	28.9	4	16.0
Primary 3	1	3.5	3.5	0	0.0
Primary 20	1	8.7	8.7	2	8.0
Primary 22	2	7.5	15.0	3	12.0
Primary 24	1	2.8	2.8	0	0.0
Primary 49	1	7.0	7.0	1	4.0
Primary 57	2	12.0	24.0	5	20.0
Primary 60	2	8.3	16.5	3	12.0
Total Primary	**14**		**106.4**	**18**	**72.0**

Four-mile segment analysis was based on a sample size of 120 rumble strip and control segments covering 480.0 miles of Interstate and primary highway or approximately seventy-nine percent of the global base sample.

DATA INPUT CRITERIA

Crash Data

Crash data for each route in total was supplied by MDT. Data not included within the study segment's boundaries was discarded along with other extraneous information such as junction-related, multi-vehicle crashes, road conditions other than dry and wet, and crash types other than single vehicle off-road. The following crash data was selected from MDT crash records for input to the study analysis:

Crash Route & Mile Post
County & City Codes
Crash ID Number
Date & Time
Number of Injuries and Fatalities
Weather Conditions
Roadway Wet or Dry
Light Conditions
Day of Week
Grade & Alignment
Drivers Age & Sex
Contributing Circumstances
Car/Truck Body Style
First & Most Harmful Events

The total numbers of before and after crash events for rumble strip and control segments included within the study segments were:

	Interstate	Primary
Global Off-road	1025	166
Global Roll-over	458	62
Four-mile Off-road	901	117
Four-mile Roll-over	407	52

Time Periods

A time period of 3 years was used to establish the before and after crash experience within the analysis. Since the earliest date of documented rumble strip installation was in 1993, and the latest in 1998, all crash data from 1990 to 2001 was provided. Typically, beginning and ending dates of construction includes a 2 to 3 year period. Because information relative to the exact date of rumble strip installation was not available, the years of construction were considered the interim years between before and after periods. Although actual rumble strip construction typically occurs at the very end of the construction period, it was concluded that construction activity prior to rumble strip installation would have the potential to affect crash events. Thus, before and after time periods were not continuous. Typical before-periods might be 1992, 1993, and 1994 and after-periods might be 1997, 1998, and 1999. There were approximately five combinations of different before and after time periods involved in the analysis. The implications of these variable time periods are discussed in the study limitations section of this report.

Sample Size

Sample size within this study was limited by the number of miles of rumble strip and control segments identified within the site selection process. In the case of Interstate routes, the number of control segments was the limiting factor. On primary routes, the number of rumble strip segments limited the sample size.

Table 2 presents the relative sample size compared to the total number of Interstate and Primary/NHS route miles in Montana. The study sample size for Interstate routes consisted of approximately thirty-five percent of the total route miles in Montana, while only four percent of the total primary/NHS routes miles were sampled.

Table 2. Shoulder Rumble Strip Study Samples

Routes	Total Miles In MT*	Study Miles**	% of Total
I-15	378	112	30%
I-90	512	171	33%
I-94	246	110	45%
Total Interstate	**1136**	**393**	**35%**
Total Primary & NHS	**5385**	**213**	**4%**

* Rural

** Global Rumble & Control

Traffic Volumes

Annual Average Daily Traffic (AADT) volumes were based on data from the MDT "Traffic by Section" bi-annual reports between 1991 and 1999. The year 2001 "Traffic by Section" report was not available at the time of the study, but MDT provided select AADT data for the years 2000 and 2001 on each study route. Weighted AADT was computed for each global and four-mile study segment within the study. Each study segment contained between 1 and 5 reported AADT values per year for various reference points reported in the "Traffic By Section" document. Vehicle miles were computed for each AADT value, in each year, and then summed and divided by the segment length and the number of years in the period, to arrive at the AADT for both before and after periods in each segment. AADT volumes were used to compute crash rates and severity rates within the analysis.

Severity Rates

The State of Montana computes severity rates by first calculating a severity index, and then multiplying said index by the corresponding accident rate. The severity index is calculated through the following formula:

$$SI = [8*(K+A) + 3*(B+C) + O] / \text{Total Number of Crashes}$$

K = *Number Fatal Crashes*
A = *Number of Incapacitating Injury Crashes*
B = *Number of Non-incapacitating Injury Crashes*
C = *Number of Possible Injury Crashes*
O = *Number of PDO Crashes*

The severity rate provides a value used to compare the relative severity of crashes among different routes, facility types, intersections, etc.

STUDY LIMITATIONS

While the principal objectives of this investigation were in fact met, uncontrolled variables inherent within the study process may have potentially limited precision, if not accuracy of the results. However, the data collection and analyses procedures used are valid and the results should be considered as representative of current off-road and rollover crash trends in the state of Montana. The most obvious study limitations and their potential effect on results are detailed in the following narratives.

Sample Sizes

Sample sizes for many of the primary segments of data in this investigation were inadequate with respect to statistical analyses. The isolation of rollover crashes combined with inherently smaller samples for the equal four-mile segments on primary roads reduced sample sizes to as few as 13 crashes. While small sample sizes are accommodated by significance testing methods, statistical breakdowns of crash occurrence characteristics such as contributing circumstance or vehicle type could not be reported with any representative degree of accuracy for such groups.

Statewide Speed Limit Changes

Other factors that may potentially have induced a certain measure of bias into this investigation were the changes in speed limit implemented in 1995 and again in 1999. The Federally mandated speed limits of 65 mph (65 mph at night) on Interstate Highways and 55 mph (55 mph at night) on other highways were repealed on November 28, 1995. From that date, until May 28, 1999, the Basic Rule speed limit governed daytime speeds on both Interstate and other Montana highways (65 mph at night on Interstate Highways, 55 mph at night on other highways). On May 28, 1999, the State Legislature imposed the current limits of 75 and 70 mph respectively (75 and 65 mph at night) for Interstate and other Montana highways. Said changes may have had a certain effect on crash behaviors over the span of time during which data was collected for this inquiry. The MDT Planning Division reported that the 85th percentile speed increased from approximately 72 mph in 1985 to approximately 80 mph in the year 2000 on the Interstate system. On Primary and NHS routes the 85th percentile speed increased from approximately 65 mph to 70 mph during the same time period. This information implies that crash data from most of the study's "before" time periods were reflective of a system with lower overall speeds. However, a statistical investigation of crash and severity rates, as a function of the calendar year that they occurred, showed no significant relationships. Therefore it is likely that any bias created as a result of the speed limit changes was negligible.

Crash Report Accuracy

The investigation of contributing circumstance brought up questions of accuracy regarding crash reports. Simple human nature dictates that at least a portion of drivers that were careless or fell asleep prior to a crash would not admit to doing so after the fact. Combined with a lack of attention to detail by officers themselves in some cases, such subjective nuances likely have compromised the validity of at least a fraction of reports, and thereby, a fraction of the data analyzed within this study.

In addition, the state accident investigation report form was changed substantially in 1996, which in most cases, is the mid-point between "before" and "after" study periods. All coding data supplied by MDT was checked to determine if pre-1996 and post-1996 data was converted to the same format. It was determined that the database was uniformly coded based on the post-1996 format. However, one potential source of error could still be associated with the form change. "Contributing Circumstances" on the pre-1996 form was applied to the crash event, while the post-1996 form had five different choices, which could be applied to each vehicle. A single data entry for "Contributing Circumstances" was used within this study's database. Thus, the overriding circumstance had to be determined, based on a logical evaluation of each accident. As an example, if contributing circumstances "Fell Asleep" and "Too Fast" were applied to one crash, it was somewhat obvious that falling asleep would be the overriding contributory cause of the crash. Most of the decisions involving "Contributory Circumstances" were easily interpreted, but since the categories changed from one period to the other, it cannot be stated with certainty that errors and/or biases do not exist in this category of crash data.

Unreported Incidents

Minor run-off-the-road crashes, which do not cause injury or disable vehicles, often go un-reported for a variety of reasons, ranging from lack of insurance to alcohol implications. These incidents, which do not appear in the crash database, could potentially have contributed substantially to the study evaluation results, as it is likely that unreported incidents are affected by rumble strips in the same proportion as reported crashes.

Installation Records

Information relative to exactly when and where rumble strips were located throughout the state could not always be provided. Records either did not exist or were unable to be located. MDT project development procedures have allowed rumble strips to be bid and installed as parts of entire projects instead of autonomously. A good deal of study effort was expended to insure that each rumble strip and control segment was a valid study site for the time period investigated. Selection of these segments, with said objective in mind, limited the total number of miles that could be included in the study. Records regarding roadway width for primary roadway segments were also suspect in some cases. Variation between reported roadway widths and actual widths also likely introduced a level of bias into the investigation, although it was not found to significantly affect the primary measures of effectiveness.

Segments of primary highway that had shoulder rumble strips installed as part of a reconstruction project were eliminated from this study. It should also be noted that there have been indications that, along with rumble strip installation, other improvements may or may not have been made to various study sections that could potentially have introduced bias into the investigation, much as reconstruction would. Because records do not accurately reflect these improvements or the magnitude of such improvements, there was little that could be done to account for them.

Study Sites

The appropriation of the study sites themselves presented another limitation. It was difficult to find equal length study and control sites that were also equivalent from the standpoint of geometrics, traffic volumes, and time period of construction. The overall number of study sections was limited by the availability of Interstate control sections (only 19% of Montana Interstate Highway miles are not equipped with rumble strips) and primary rumble strip sections (only 9% of Montana primary highway miles are equipped with rumble strips). To gauge the effect different traffic volumes had on rumble strip effectiveness, an investigation was done regarding crash and severity rates. No reliable association could be found for either measure. The three-year period each sample originated from was also investigated, in much the same way, to gauge its effect on crash frequency and severity relationships. It was found that no consistent relationship existed regarding calendar year.

Mile Post Distances

Equal four-mile study segments in this investigation were created for statistical analysis purposes. Data within each four-mile segment was extracted from records based on the milepost reference system. In certain cases however, actual distances between mileposts can vary by as much as +/-0.2 miles. Therefore it's possible that some of the four-mile segments in this investigation were not actually four miles in distance. This may affect the calculation of crash and severity rates between separate segments. It was decided that variations in actual distance between mileposts could be considered random occurrences, and that any imbalance between rumble strip and control segment distance would be minimal.

Crash & Severity Rates

Crash and severity rates are normally calculated on the basis of total traffic, while this study considered only crashes on dry and wet pavement. In this case, crash and severity rates for off-road accidents would be higher than the reported statewide rates because no attempt was made to determine proportionate traffic volumes during periods when roadway pavements were wet or dry. This study limitation should be considered when attempting to predict crash and severity rate reductions on roadways where only total off-road crash and severity rates are known.

INTERSTATE SHOULDER RUMBLE STRIPS

The analysis of crash data in this investigation was conducted for both Interstate and primary roadway study sections. Analyses included descriptive and comparative statistical inquiries regarding the number of crashes, as well as crash and severity rates for before and after conditions, on rumble strip and control groups, as the primary focus. Within this report, "Before" refers to a 3 year crash period before shoulder rumble strips were installed and "After" refers to a 3 year crash period after the installation. Control sections were assigned to corresponding rumble strip sections based on similarity of roadway characteristics and then analyzed to provide a basis for those comparisons. Control segment analysis involved the same before and after periods as the corresponding rumble strip segments. Also, roadway segments were considered both globally, without regard to length, and in equal four-mile segments to allow statistical significance testing.

Interstate crash data was collected for 393.4 miles of roadway from Interstates 15, 90, and 94 in the state of Montana. Global analyses covered 196.7 miles of Interstate roadway through 17 rumble strip and control segments, while the 4-mile segment analyses included 168.0 miles divided into 42 rumble strip and control segments.

Descriptive Statistics Using Global Data

Basic summary statistics from global crash data were used for descriptive statistics. This analysis was completed to determine if any individual variables should be investigated in more detail. Before and after period crash statistics were calculated in relation to factors such as traffic volume, light conditions, driver age, vehicular body style, and contributing circumstance.

Crash Frequency and Severity Rates

Crash occurrence and severity rates, prior to and after rumble strip implementation, broken down by Interstate highway route, for global off-road and rollover crash data on a global segment scale, can be found in Tables 3 and 4.

Crash occurrence and severity rates for individual segments can be found in the Appendix (Tables A-3 and A-4).

Global off-road crashes (see Table 3) realized an improvement in both frequency (-5.5%) and severity (-24.4%) from the before to after period for 17 Interstate rumble strip segments. Corresponding control segments produced a 6.4 percent increase overall in crash rate, while severity rate decreased by 9.6 percent. The relationships indicate that the addition of rumble strips may have improved roadway safety for motorists as far as both crash frequency and severity were concerned.

Table 3. Global Off-road Interstate Crash Summary

Interstate Routes (# of Segments)		Rumble Strip Segments		Control Segments	
		Avg. Crash Rate	Avg. Severity Rate	Avg. Crash Rate	Avg. Severity Rate
I-15 (4)	Before	0.218	0.783	0.218	0.823
	After	0.189	0.424	0.394	1.162
% Change		**-13.3%**	**-45.8%**	**80.7%**	**41.2%**
I-90 (9)	Before	0.223	0.678	0.294	1.031
	After	0.208	0.559	0.240	0.784
% Change		**-6.7%**	**-17.6%**	**-18.4%**	**-24.0%**
I-94 (4)	Before	0.201	0.804	0.229	0.918
	After	0.219	0.595	0.297	0.826
% Change		**9.0%**	**-26.0%**	**29.7%**	**-10.0%**
Interstate Totals (17)	Before	0.219	0.716	0.265	0.965
	After	0.207	0.541	0.282	0.872
% Change		**-5.5%**	**-24.4%**	**6.4%**	**-9.6%**

Regarding rollover crashes from global segments of Interstate roadway (see Table 4), results did not follow the same trend. Crash rates for rumble strip segments increased by 14.5 percent from the before to after period, while severity increased by 7.2 percent. Crash rates for the parallel control segments increased similarly, by 15.3 percent, while severity decreased by a margin of 2.9 percent. Here the indication is that rumble strip implementation did not radically affect crash rate, while severity rates increased.

Table 4. Global Rollover Interstate Crash Summary

Interstate Routes (# of Segments)		Rumble Strip Segments		Control Segments	
		Avg. Crash Rate	Avg. Severity Rate	Avg. Crash Rate	Avg. Severity Rate
I-15 (4)	Before	0.077	0.312	0.086	0.469
	After	0.087	0.260	0.203	0.731
% Change		**13.0%**	**-16.7%**	**136.0%**	**55.9%**
I-90 (9)	Before	0.069	0.271	0.141	0.579
	After	0.091	0.350	0.118	0.486
% Change		**31.9%**	**29.2%**	**-16.3%**	**-16.1%**
I-94 (4)	Before	0.103	0.432	0.112	0.581
	After	0.067	0.298	0.161	0.499
% Change		**-35.0%**	**-31.0%**	**43.8%**	**-14.1%**
Interstate Totals (17)	Before	0.076	0.305	0.124	0.556
	After	0.087	0.327	0.143	0.540
% Change		**14.5%**	**7.2%**	**15.3%**	**-2.9%**

The considerable variation across the three Interstate routes studied, for all off-road crashes as well as rollover crashes, may explain in part why some states have realized dramatically different results than others through previous investigations. Cause of the variation is difficult to determine. Coincidental differences in terrain, demographic of the driver population, and other factors may be accountable, yet to validate such a statement, further investigation would be necessary.

Roadway Characteristics

The significance of various roadway characteristics linked to the crashes in this study, including surface conditions and roadway alignment, was investigated and revealed no palpable relationships. Neither vertical and horizontal roadway curvatures, nor wet/dry roadway surface conditions, yielded correlations in crash experience before and after rumble strip implementation.

Light Conditions

The investigation of light conditions for Interstate off-road crashes implied a substantial decrease in the percentage of crashes occurring at night. For rumble strip segments of roadway, nighttime incidents comprised 40.2 percent (88 crashes) of all off-road crashes before treatment and just 28.9 percent (67 crashes) after (see Figure 1). A similar magnitude of decrease was not evident for control segments of roadway (see Figure 2), indicating that the implementation of rumble strips may have effectively decreased nighttime crash rates. Comparable, albeit more dramatic, results were realized regarding rollover crashes specifically. For the rumble strip segments of roadway, nighttime rollover crash occurrences were reduced from 40.3 percent (31 crashes) to 23.5 percent (23 crashes) through the implementation of rumble strips, while over the same period of time, frequencies increased from 27.3 percent (35 crashes) to 33.9 percent (56 crashes) for the control segments of Interstate roadway.

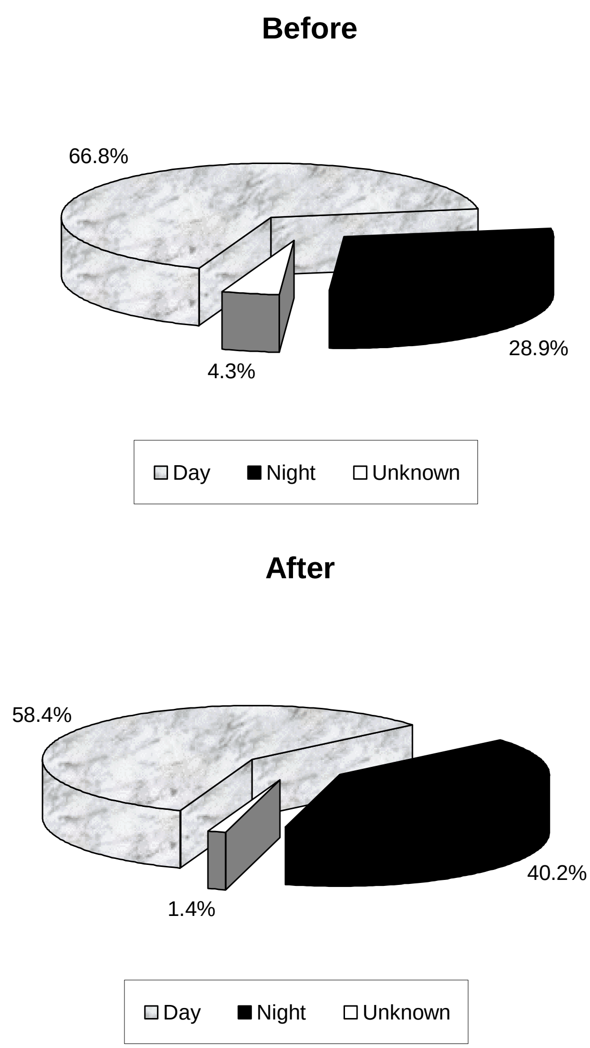
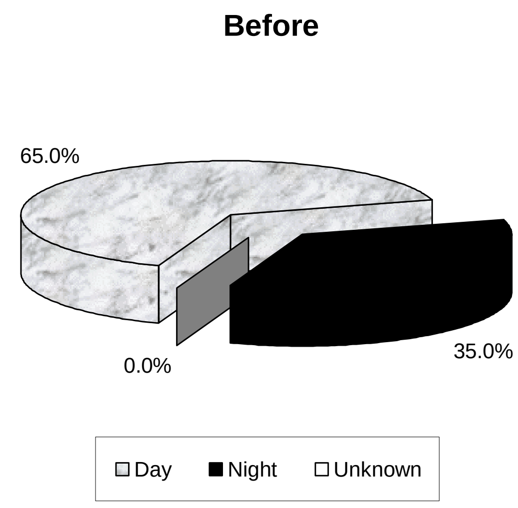


Figure 1. Off-road Crash Light Conditions – Rumble Strip Segment



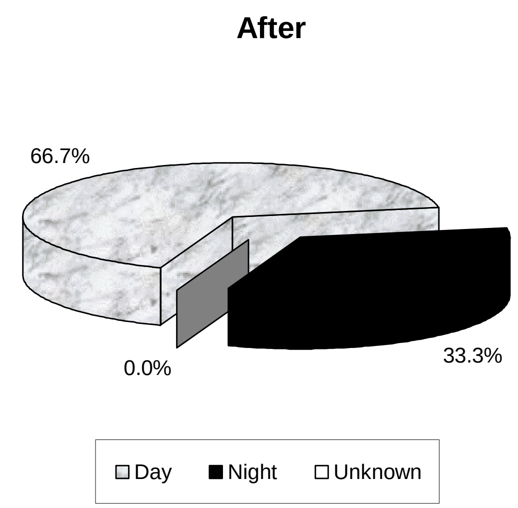


Figure 2. Off-road Crash Light Conditions – Control Segment

Drivers

Driver sex and age were investigated and it was found that no substantial before/after relationship existed regarding sex. As far as driver age, it was found that drivers over the age of 50 may have significantly benefited from the implementation of rumble strips (see Figure 3). A four percent decrease in the number of such drivers involved in general off-road crashes was found for the rumble strip segments of roadway after the implementation of rumble strips, while

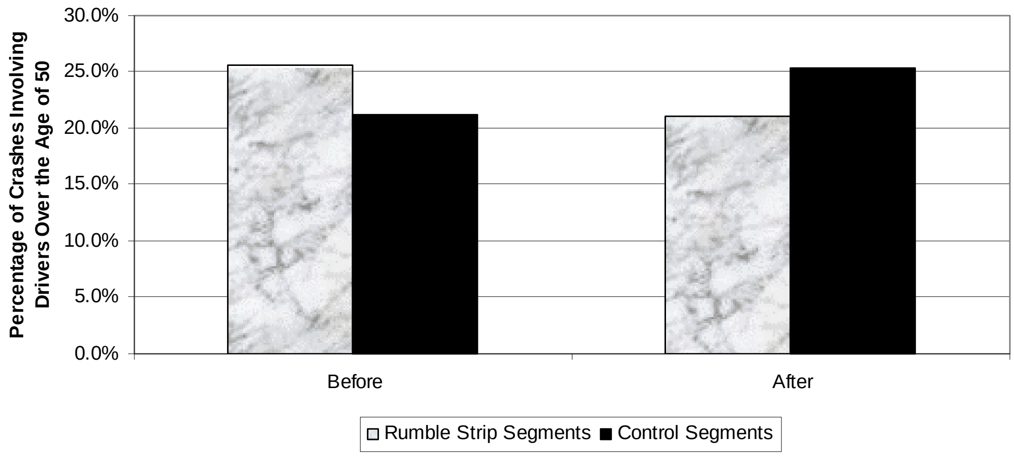


Figure 3. Global Off-road Interstate Crashes Involving Drivers Over the Age of 50

control segments provided a four percent increase during the same period of time.

Isolating rollover crashes, an overall decrease in crashes for drivers over the age of 50 occurred for both the rumble strip (3.7%) and control segments (8.5%), although it should be noted that the more dramatic decrease occurred for the control segments. A similar pattern was evident for drivers under the age of 21 (see Figure 4). Prior to implementation, 17.8 percent (39 crashes) of Interstate off-road crashes on rumble strip segments of roadway involved drivers under 21. Once rumble strips were in place, that number dwindled slightly to 15.5 percent (36 crashes). For control segments, the opposite was true. Drivers under the age of 21 involved in before-crashes numbered 20.1 percent (55 crashes) for the Interstate segment, increasing to 23.5 percent (77 crashes) for the after period.

Comparable relationships prevailed for rollover crashes as well, indicating that young drivers may also have benefited from rumble strip usage. No significant relationship was evident for drivers between the ages of 21 and 50 years.

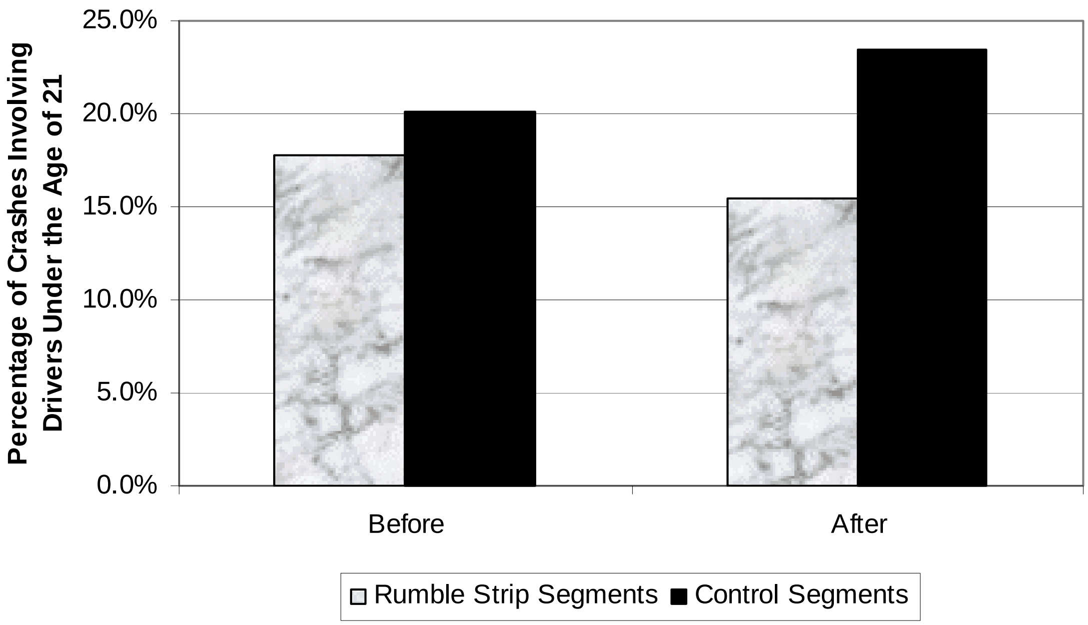


Figure 4. Global Off-road Interstate Crashes Involving Drivers Under the Age of 21

Vehicle Type

The consideration of vehicle type yielded a pair of interesting relationships for Interstate roadways. Sport utility vehicles (SUVs) failed to account for a single off-road crash on either the rumble strip or control segments of roadway prior to the advent of rumble strip installation circa 1995. In the after period, SUVs comprised 7.8 percent of off-road crashes for the rumble strip segments and 4.9 percent for the control segments. The absence of SUVs from before-period analysis periods is primarily due to the fact that the accident investigators report form changed in 1996. Prior to 1996 the only similar category was "Mini Bus/ Van". The new report form has a separate category for "Sport Utility Vehicle".

Motorcycle crashes yielded a second noteworthy relationship on Interstate roadways. The analysis of off-road crashes on rumble strip sections of roadway revealed that motorcycles made up 0.5 percent (1 crash) of all crashes prior to implementation of rumble strips and 1.7 percent (4 crashes) after (see Figure 5). Contrarily, motorcycle crashes comprised 2.2 percent (6 crashes) of all off-road crashes in the before period for the control segments of roadway and 0.0 percent in the after period. Similar relationships existed for rollover crashes specifically as well. Again, the small number of crashes within the study indicates that observed occurrences could be entirely a matter of coincidence, rather than a cause and effect relationship with rumble strip implementation.

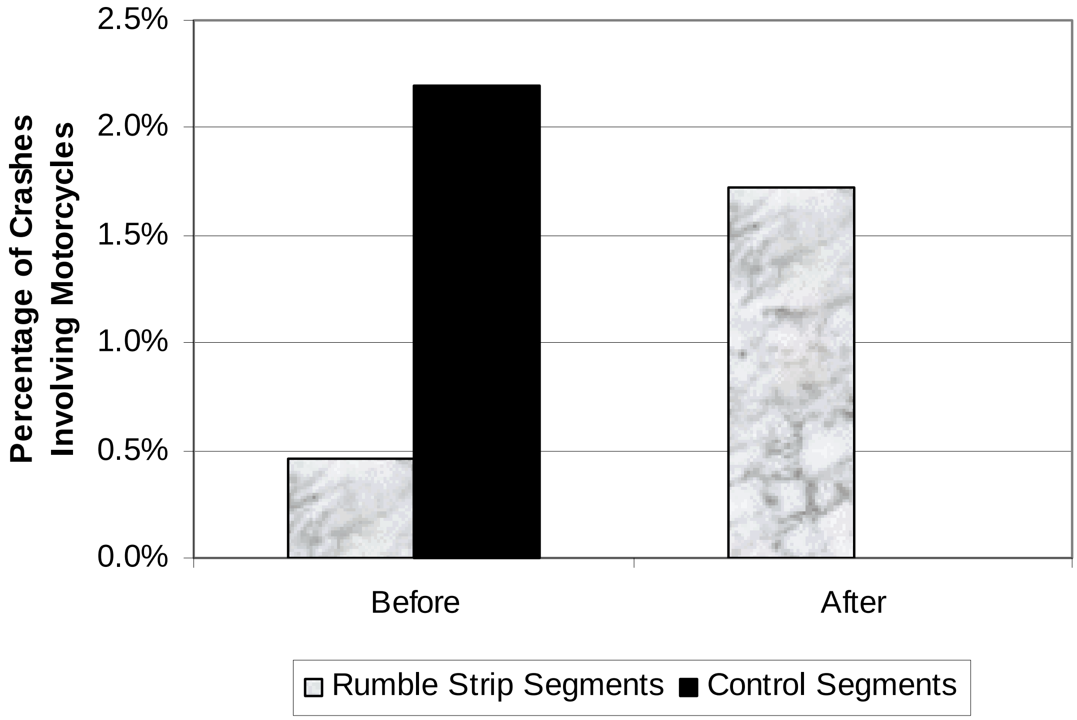


Figure 5. Global Off-road Interstate Crashes Involving Motorcycles

None of the other vehicle types investigated showed any substantial changes in number of crashes or crash rates, although the number of crashes involving pickups and wagons were both found slightly less after rumble strip implementation.

Contributing Circumstance

There are a number of contributing circumstances that are used by state officials to describe conditions that likely contribute to off-road crashes on Montana's highways. Crashes that can be most obviously avoided through the efforts of rumble strip technology are probably those caused by inattentive driving and falling asleep behind the wheel. Alcohol involvement and careless driving are two of the other prevalent contributors. Through this investigation, it was found that inattentive driving was listed as a contributing circumstance for 31.1 percent (68 crashes) of all off-road crashes on rumble strip segments in the before period (see Figure 6). Once rumble strips were installed, that figure dropped to just 19.0 percent (44 crashes). Control sections of Interstate roadway experienced a nearly identical level of improvement over the same period of time, clouding the notion that rumble strips were entirely responsible for the decrease in crashes.

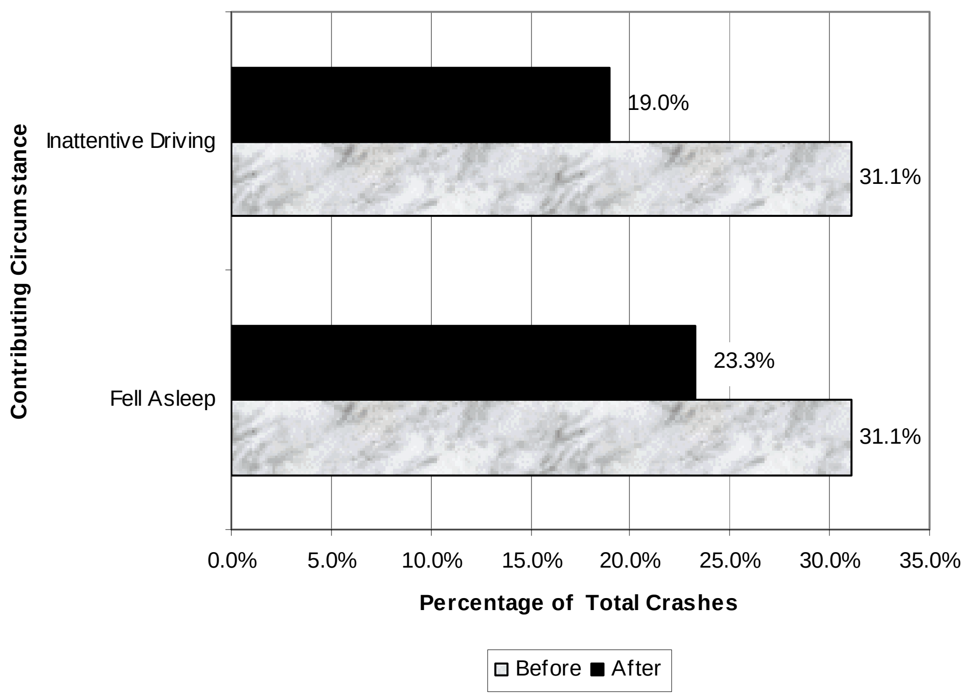


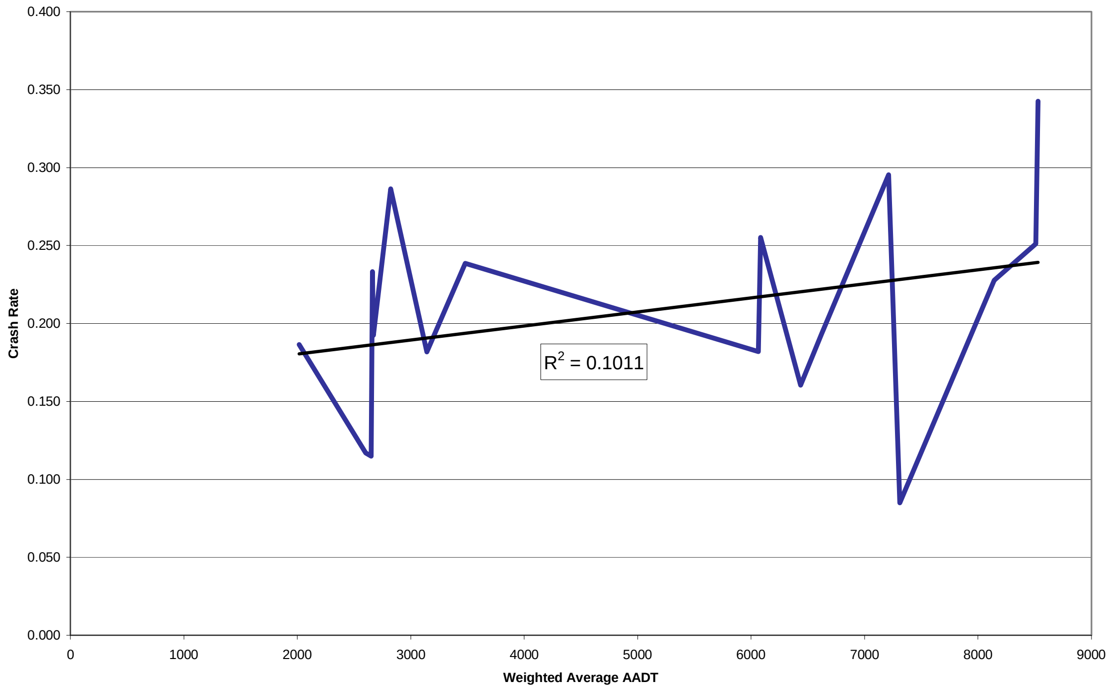
Figure 6. Global Off-road Interstate Crashes by Contributing Circumstance

Parallel relationships were evident for rollover crashes as well, with a dramatic reduction in the number of crashes caused by inattentive driving realized across the before and after analysis periods. It should be noted that such data may be inherently skewed due to the subjective nature of its source, state crash reports. As previously stated within this report, changes in reporting format for contributing circumstances in 1996 may have also skewed the results of this analysis.

“Falling asleep” was listed as a contributing circumstance for 31.1 percent (68 crashes) of all Interstate off-road crashes on the rumble strip sections of roadway for the before period (see Figure 6). The after period saw that number fall to 23.3 percent (54 crashes). For the control sections, falling asleep received blame in 25.5 percent (70 crashes) of cases beforehand and 27.2 percent (89 crashes) after, indicating that rumble strips may have proved effective in reducing the number of such crashes in the rumble strip sections. Similar patterns were found regarding rollover crashes before and after rumble strip implementation.

Traffic Volumes

An investigation of crash and severity rates as a function of weighted-average Annual Average Daily Traffic (AADT) proved inconsequential. Historically, it has often been reported that an obvious relationship exists between crash frequency and increased traffic volumes, however none could be found for either crash rate or severity using the global off-road segment of data from this investigation (see Figure 7). For example, although the trend-line shown in Figure 7 implies that a linearly escalating relationship might exist between crash rate and AADT, the low R^2 value indicates that only about 10 percent of the variability in the response is actually explained through the corresponding regression equation.



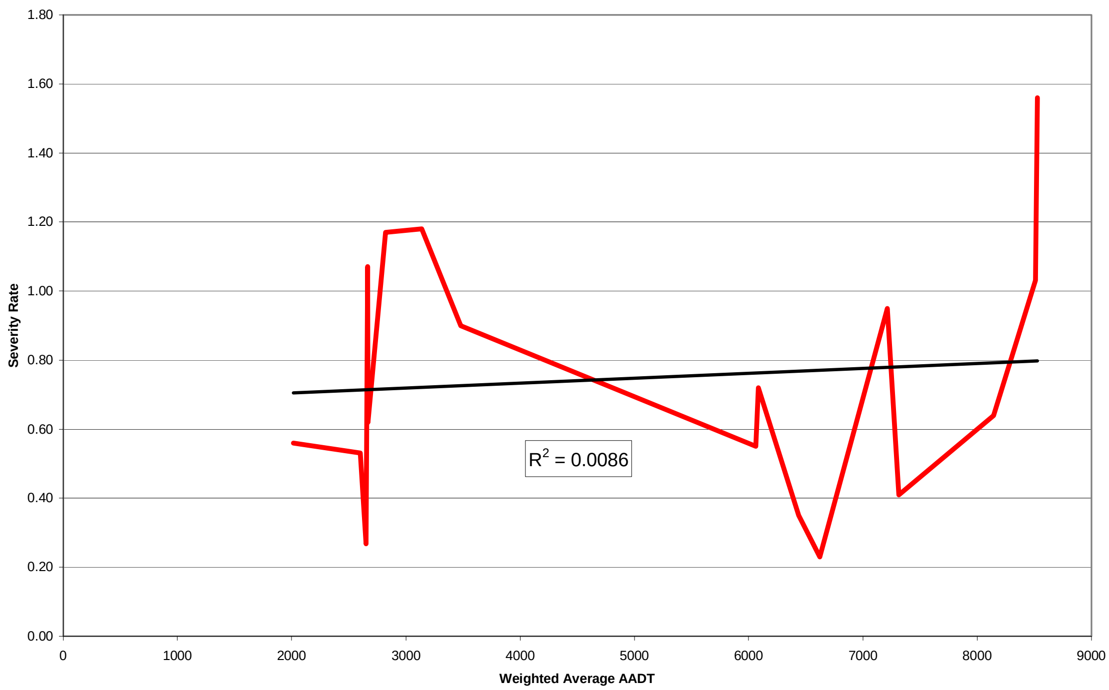


Figure 7. Global Before Period Interstate Off-road Crash and Severity Rates vs. Weighted Average AADT

Comparative Statistics Using Segment Data

For the comparative portion of the analysis, data segments were further broken down into equal four-mile segments to allow for testing of several statistical relationships in addition to the direct comparison of crash and severity rates. From a statistical standpoint, a pair of general relationships was examined:

1. Crash numbers, frequencies, and severities before vs. after rumble strip implementation

2. Change in number of crashes, crash frequencies and crash severities for control vs. rumble strip segments

For the before and after comparison, significance was established through a hypothesis testing procedure known as the paired t-test. The paired t-test is a variation of a basic methodology known as the two-sample t-test. The two-sample t-test allows for the inference on a difference in means of two normally distributed samples without a required knowledge of their variances. In this case, a hypothesis test was conducted for which the null hypothesis stated that the difference in the mean number of crashes, crash rates or severity rates for the before and after periods was equal to zero. The alternative hypothesis stated that the difference in means did not equal zero, or in other words that there was a change between the before and after period, for whatever reason. Significance of that change was then established by comparing a calculated test statistic, t, to a tabled value corresponding to the number of observations at a specified confidence interval. For the purpose of this investigation, a 95 percent confidence interval was employed. The “paired” variation was employed because data was collected for before and after periods from the same segments, nullifying independence.

Control vs. treatment section comparisons were made using a contingency table approach based upon the Chi-squared distribution. The technique is commonly used to test for an association between two categorical variables. In this case, those variables were timeframe, relative to rumble strip implementation, and roadway segment, whether it be rumble strip or control. Again, a 95 percent confidence interval was utilized and in order to obtain a measure of the degree of effectiveness of rumble strip implementation, a statistic referred to as the odds ratio (U) or cross product ratio was calculated. The odds ratio in this case consists simply of a ratio of the crashes at the control sites from before to after, divided by the similar ratio of crashes at the rumble strip sites. In this case, the measure allowed for the comparison of before and after data on an equivalent basis through temperance of the relationship as to the level of exposure for each case. The apparent effectiveness (E) of rumble strip implementation was then expressed in terms of the odds ratio and, in order to determine if that apparent effectiveness occurred by chance, the Z-statistic, based upon the normal distribution, was called into service. In all, this procedure allowed for a determination of difference between performances for the rumble strip and control segments, as well as a projection of the actual effectiveness of the measure in question.

Crash and Severity Rates

Crash and severity rates broken down by Interstate highway route for off-road and rollover crashes on a 4-mile segment scale can be found in Tables 5 and 6.

Four-mile off-road crashes (see Table 5) realized an improvement in both rate (-7.0%) and severity (-29.0%) from the before to after period for 17 Interstate rumble strip segments. Conversely, corresponding control segments witnessed a rise in crash rate of 8.1 percent, while severity decreased by just 7.2 percent. As in the case of global segment analysis, a marked relative improvement from the before to after period indicates that rumble strips may have been successful in making the Interstate roadways in this study safer.

Rollover crash analysis results were found to be somewhat ambiguous (see Table 6). The average crash rate for interstate rumble strip segments increased by a magnitude of 10.3 percent, while severity had no change. The corresponding control segments also showed an increase in crash rate, of 16.7 percent, suggesting that rumble strips may have reduced crash frequency slightly. Crash severity for the control segment however, showed just a 2.7 percent improvement from the before to after period, slightly better than for the rumble strip sections.

Table 5. 4-mile Off-road Interstate Crash Summary

Interstate Routes (# of Segments)		Rumble Strip Segments		Control Segments	
		Avg. Crash Rate	Avg. Severity Rate	Avg. Crash Rate	Avg. Severity Rate
I-15 (12)	Before	0.234	0.818	0.224	0.839
	After	0.204	0.473	0.431	1.299
% Change		**-12.8%**	**-42.2%**	**92.4%**	**54.8%**
I-90 (17)	Before	0.232	0.702	0.304	1.082
	After	0.208	0.522	0.239	0.821
% Change		**-10.3%**	**-25.6%**	**-21.4%**	**-24.1%**
I-94 (13)	Before	0.205	0.838	0.237	0.965
	After	0.231	0.628	0.309	0.869
% Change		**12.7%**	**-25.1%**	**30.4%**	**-9.9%**
Interstate Totals (42)	Before	0.227	0.748	0.272	1.004
	After	0.211	0.531	0.294	0.932
% Change		**-7.0%**	**-29.0%**	**8.1%**	**-7.2%**

Table 6. 4-mile Rollover Interstate Crash Summary

Interstate Routes (# of Segments)		Rumble Strip Segments		Control Segments	
		Avg. Crash Rate	Avg. Severity Rate	Avg. Crash Rate	Avg. Severity Rate
I-15 (12)	Before	0.076	0.302	0.080	0.406
	After	0.09	0.270	0.213	0.806
% Change		**18.4%**	**-10.6%**	**166.3%**	**98.5%**
I-90 (17)	Before	0.072	0.279	0.156	0.673
	After	0.088	0.327	0.129	0.530
% Change		**22.2%**	**17.2%**	**-17.3%**	**-21.2%**
I-94 (13)	Before	0.102	0.448	0.119	0.615
	After	0.07	0.314	0.165	0.523
% Change		**-31.4%**	**-29.9%**	**38.7%**	**-15.0%**
Interstate Totals (42)	Before	0.078	0.315	0.132	0.603
	After	0.086	0.315	0.154	0.587
% Change		**10.3%**	**0.0%**	**16.7%**	**-2.7%**

Rumble Strip Segments:

Before vs. After Crashes, Crash Rates and Severity Rates

Hypothesis testing of before and after crash, crash rate, and severity rate data was completed for rumble strip segments from Interstate roadways, broken into four-mile segments. Curiously, not a single significant relationship was found at a 95 percent confidence interval for any of the three measures regarding either off-road or rollover crashes (see Table 7). This indicates that from a statistical standpoint, there were no significant differences in number of crashes, crash rates, or crash severities from the time before rumble strips were implemented to after, without consideration of the control sections.

Table 7. 4-mile Interstate Rumble Strip Segment Before vs. After Paired t-test Results

	Off-road Crashes			Rollover Crashes		
	95% C.I.	t statistic	2-tailed P	95% C.I.	t statistic	2-tailed P
# of Crashes	-2.631 to 0.345	-1.55	0.129	-1.856 to 0.190	-1.65	0.108
Crash Rate	-0.120 to 0.029	-1.23	0.227	-0.096 to -0.012	-1.58	0.122
Severity Rate	-0.244 to 0.382	0.45	0.658	-0.268 to 0.251	-0.06	0.949

Rejection Level (t) = + / - 1.960
α = 0.05

Control Segments: Before vs. After Crashes, Crash Rates and Severity Rates

A similar investigation of before and after relationships for the control segments of roadway produced similar results (see Table 8). No significant relationships were found from the before to after period, through the paired t-test analysis.

Table 8. 4-mile Interstate Control Segment Before vs. After Paired t-test Results

	Off-road Crashes			Rollover Crashes		
	95% C.I.	t statistic	2-tailed P	95% C.I.	t statistic	2-tailed P
# of Crashes	-1.538 to 1.157	-0.29	0.777	-0.909 to 0.147	-1.46	0.153
Crash Rate	-0.066 to 0.077	0.16	0.876	-0.036 to 0.028	-0.24	0.808
Severity Rate	-0.046 to 0.470	1.66	0.1041	-0.149 to 0.198	0.29	0.776

Rejection Level (t) = + / - 1.960
α = 0.05

Rumble Strip Segment vs. Control Segment Significance Testing

Significance testing to qualify any differences between the rumble strip and control Interstate segments included in the analysis proved only slightly more positive from a statistical standpoint than did the comparison of before and after data. A relative reduction, measured as apparent effectiveness (E), of 14.0 percent (see Table 9) was calculated for 4-mile segments and, although the difference was not found to be significant from a statistical standpoint, the rate was thought to be representative of the difference in behaviors brought about through the implementation of rumble strips. A relative reduction of 5.5 percent regarding the isolation of rollover crash rate was observed for 4-mile rumble strip and control sections and was also found to be insignificant statistically.

A 23.5 percent relative reduction in the Interstate crash severity rate was realized for 4-mile treatment sections over their control section counterparts and in this case, the difference was found to be significant, at a 95 percent confidence interval (see Table 9). Rollover crash severity rates realized a 2.7 percent relative increase from the before to after period, albeit not to a statistically significant degree.

Table 9. 4-mile Interstate Rumble Strip vs. Control Segment Contingency Table Results

	Off-road Crashes			Rollover Crashes		
	χ^2 statistic	p	E (% relative difference)	χ^2 statistic	p	E (% relative difference)
# of Crashes	1.00	0.3172	-13.4%	0.02	0.9002	-4.7%
Crash Rate	1.26	0.2622	-14.0%	0.04	0.8495	-5.5%
Severity Rate	***13.36***	***0.0003***	***-23.5%***	0.05	0.8231	2.7%

Rejection Level (χ^2) = 3.841 (p = 0.05)
α = 0.05

Success, to a varying degree, seems to have been realized for interstate highways through the implementation of shoulder rumble strips, at least for the segments of roadway examined in this study. Off-road crashes realized an impressive relative improvement for both crash rate and severity, while for rollover crashes, only minor differences were evident.

TWO-LANE PRIMARY HIGHWAY SHOULDER RUMBLE STRIPS

Primary crash data was collected for 212.8 miles of roadway from Primaries 1, 3, 20, 22, 24, 29, 57 and 60 in the state of Montana. Global analyses covered 106.4 miles of roadway using 14 rumble strip and control segments, while 4-mile analyses included 72.0 miles divided into 18 rumble strip and control segments.

Descriptive Statistics Using Global Data

Again, basic summary statistics from global crash data were used for descriptive statistics. This analysis was completed to determine if any individual variables should be investigated in more detail. Before and after period crash statistics were calculated in relation to factors such as traffic volume, light conditions, driver age, vehicular body style, and contributing circumstance.

Crash Frequency and Severity Rates

Crash frequency and severity rates broken down by primary highway route for off-road and rollover crashes on a global segment scale can be found in Tables 10 and 11. Global off-road crashes (see Table 10) realized an improvement in rate (-17.6%), while severity (+3.5%) increased from the before to after period for 14 two-lane primary rumble strip segments. Corresponding control segments produced no change overall in crash rate, while severity rate decreased by 23.2 percent. The relationship indicates that the addition of rumble strips may have improved roadway safety for motorists as far as crash frequency is concerned, but an increase in crash severity rates occurred at the same time.

Regarding rollover crashes from global segments of primary roadway (see Table 11), results were inverted. Crash rates for rumble strip segments increased by 13.3 percent from the before to after period, while severity rates increased by 73.0 percent. Crash and severity rates for the parallel control segments decreased by 17.3 and 11.5 percent, respectively. Here the indication is that rumble strip implementation along with a number of other factors may have caused a noticeable increase in both rollover crash frequency and severity for primary roadways analyzed within the study segments.

Table 10. Global Off-road Primary Crash Summary

Primary Routes (# of Segments)		Rumble Strip Segments		Control Segments	
		Avg. Crash Rate	Avg. Severity Rate	Avg. Crash Rate	Avg. Severity Rate
P-1 (4)	Before	0.070	0.261	0.156	0.402
	After	0.158	0.724	0.130	0.330
% Change		**125.7%**	**177.4%**	**-16.7%**	**-17.9%**
P-3 (1)	Before	0.180	1.441	0.217	1.732
	After	0.000	0.000	0.000	0.000
% Change		**-100.0%**	**-100.0%**	**-100.0%**	**-100.0%**
P-20 (1)	Before	0.199	0.637	0.334	0.917
	After	0.034	0.034	0.414	0.552
% Change		**-82.9%**	**-94.7%**	**24.0%**	**-39.8%**
P-22 (2)	Before	0.344	1.377	0.705	3.670
	After	0.290	1.625	0.726	1.740
% Change		**-15.7%**	**18.0%**	**3.0%**	**-52.6%**
P-24 (1)	Before	0.144	0.432	0.432	1.727
	After	0.315	1.051	0.315	0.526
% Change		**118.8%**	**143.3%**	**-27.1%**	**-69.5%**
P-49 (1)	Before	0.669	1.242	0.615	1.231
	After	0.225	0.375	0.468	1.483
% Change		**-66.4%**	**-69.8%**	**-23.9%**	**20.5%**
P-57 (2)	Before	0.083	0.311	0.227	1.096
	After	0.074	0.204	0.194	0.647
% Change		**-10.8%**	**-34.4%**	**-14.5%**	**-41.0%**
P-60 (2)	Before	0.176	0.493	0.189	0.377
	After	0.158	0.885	0.464	1.096
% Change		**-10.2%**	**79.5%**	**145.5%**	**190.7%**
Primary Totals (14)	Before	0.165	0.541	0.240	0.809
	After	0.136	0.560	0.240	0.621
% Change		**-17.6%**	**3.5%**	**0.0%**	**-23.2%**

Roadway Conditions

The effects of wet/dry surface conditions and vertical and horizontal roadway alignment were again found to be inconsequential across the before and after periods. Roadway pavement widths become a relevant factor in this case as well, because they are so highly variable for primary roads in the state of Montana. A narrowed shoulder width may inhibit the effectiveness of rumble strips by minimizing the recovery area beyond the marking or by simply compromising the installation of rumble strips in the first place. Therefore, roadway pavement widths were examined to gage their effect on rumble strip

Table 11. Global Rollover Primary Crash Summary

Primary Routes (# of Segments)		Rumble Strip Segments		Control Segments	
		Avg. Crash Rate	Avg. Severity Rate	Avg. Crash Rate	Avg. Severity Rate
P-1 (4)	Before	0.035	0.190	0.022	0.070
	After	0.113	0.590	0.020	0.160
% Change		**222.9%**	**210.5%**	**-9.1%**	**128.6%**
P-3 (1)	Before	0.000	0.000	0.000	0.000
	After	0.000	0.000	0.000	0.000
% Change		**0.0%**	**0.0%**	**0.0%**	**0.0%**
P-20 (1)	Before	0.040	0.120	0.083	0.080
	After	0.000	0.000	0.069	0.070
% Change		**-100.0%**	**-100.0%**	**-16.9%**	**-12.5%**
P-22 (2)	Before	0.057	0.170	0.423	2.680
	After	0.058	0.460	0.290	0.580
% Change		**1.8%**	**170.6%**	**-31.4%**	**-78.4%**
P-24 (1)	Before	0.000	0.000	0.144	0.144
	After	0.105	0.840	0.000	0.000
% Change		**Infinite**	**Infinite**	**-100.0%**	**-100.0%**
P-49 (1)	Before	0.478	0.860	0.513	1.130
	After	0.075	0.075	0.468	0.858
% Change		**-84.3%**	**-91.3%**	**-8.8%**	**-24.1%**
P-57 (2)	Before	0.021	0.062	0.095	0.529
	After	0.019	0.019	0.065	0.275
% Change		**-9.5%**	**-69.4%**	**-31.6%**	**-48.0%**
P-60 (2)	Before	0.070	0.388	0.141	0.236
	After	0.126	0.853	0.169	0.633
% Change		**80.0%**	**119.8%**	**19.9%**	**168.2%**
Primary Totals (14)	Before	0.060	0.200	0.098	0.348
	After	0.068	0.346	0.081	0.308
% Change		**13.3%**	**73.0%**	**-17.3%**	**-11.5%**

performance for off-road and rollover crashes. Results were inconclusive, as crash rate did not seem to be affected significantly through rumble strip implementation, no matter the roadway width (see Figures 8-11 for off-road crash results), for off-road or rollover crashes. Severity rates did show an apparent dependence upon roadway width, yet they were found to be higher on wider roads, a curious result not readily explained. It is likely that this finding is merely a matter of coincidence.

Light Conditions

Nighttime crash rates on primary roadways within this study did not prove to benefit from the implementation of rumble strips in the way that they did on Interstate roadways (see Figures 12 and 13). During the before period, 54.5 percent (18 crashes) of all off-road crashes on rumble strip segments of roadway occurred at night. Once rumble strips were in place, that percentage fell slightly

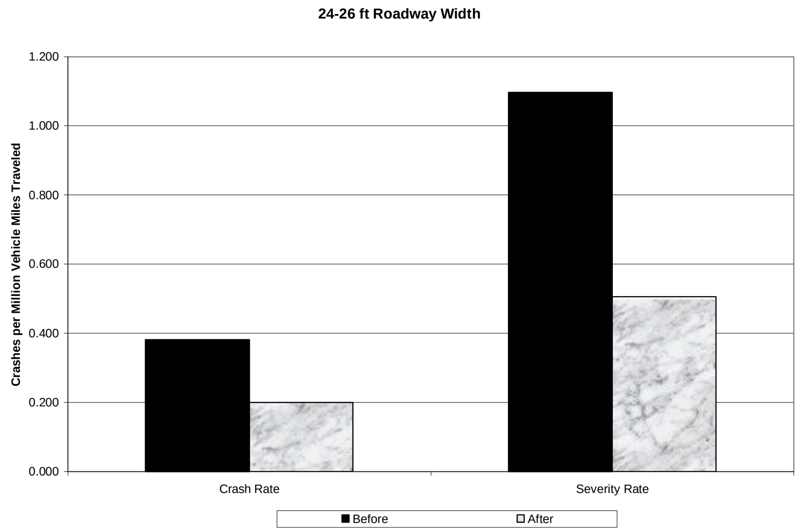


Figure 8. Off-road Crash and Severity Rates Before and After Rumble Strip Implementation for Two-lane Primary Roadway Widths of 24-26 ft (1-2 ft shoulders). – 4 study segments

Figure 9. Off-road Crash and Severity Rates Before and After Rumble Strip Implementation for Two-lane Primary Roadway Widths of 32 ft (4 ft shoulders). – 6 study segments

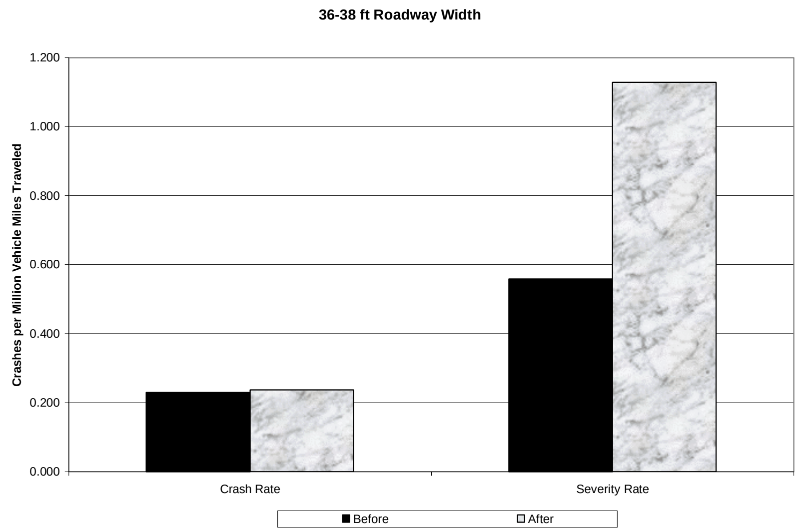


Figure 10. Off-road Crash and Severity Rates Before and After Rumble Strip Implementation for Two-lane Primary Roadway Widths of 36-38 ft (6-7 ft shoulders). – 4 study segments

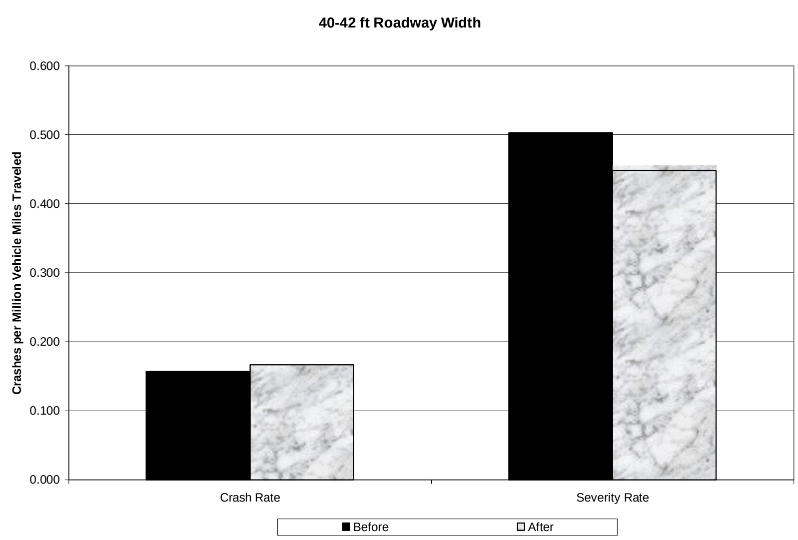
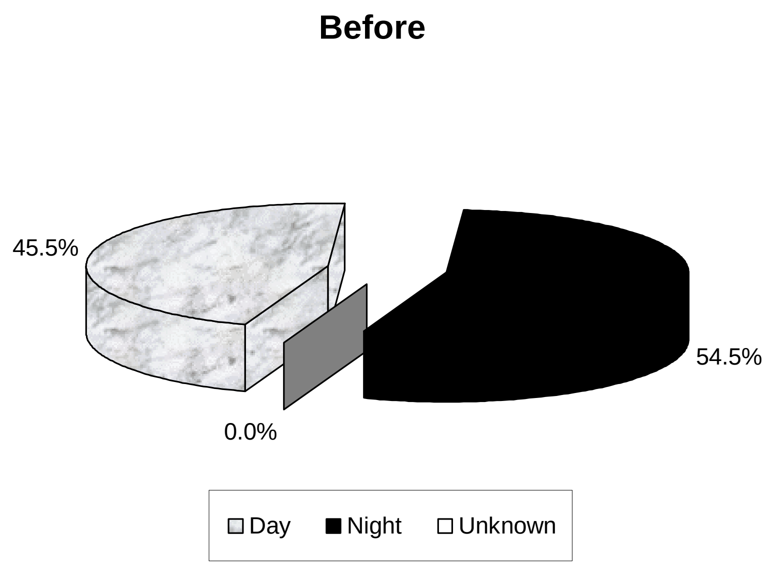


Figure 11. Off-road Crash and Severity Rates Before and After Rumble Strip Implementation for Two-lane Primary Roadway Widths of 40-42 ft. – 9 study segments



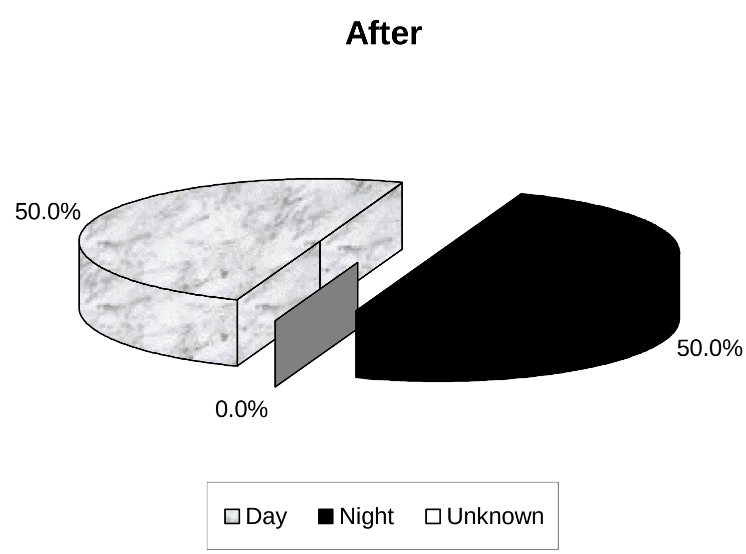


Figure 12. Off-road Crash Light Conditions – Rumble Strip Segment

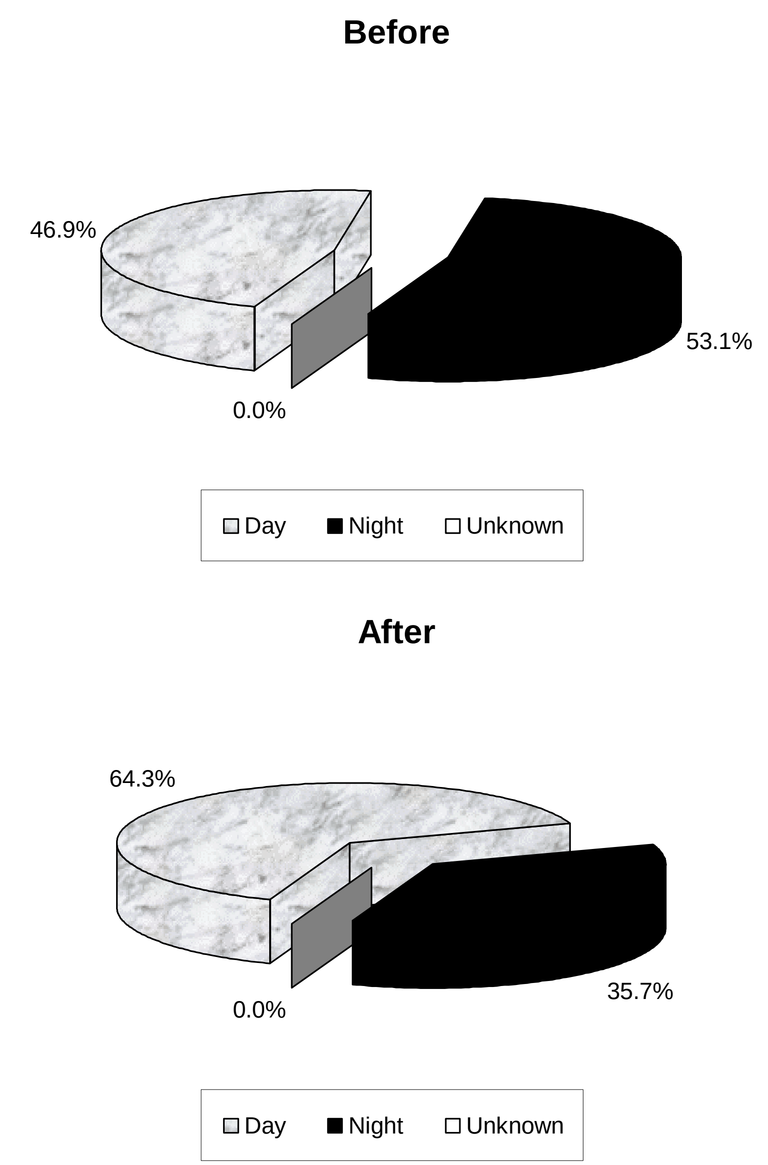


Figure 13. Off-road Crash Light Conditions – Control Segment

to 50.0 percent (14 crashes), while on control segments of roadway, a pre-treatment figure of 53.1 percent (26 crashes) fell to 35.7 percent (20 crashes). It would seem that a more dramatic improvement should have been realized for the rumble strip segments, yet because the data is of such a small magnitude, it is difficult to justify any such conclusions. Comparable results were realized regarding rollover crashes specifically. For the rumble strip segments of roadway, nighttime rollover frequencies were reduced from 46.2 percent (6 crashes) to 42.9 percent (6 crashes) on rumble strip segments, while over the same period of time, frequencies decreased from 57.9 percent (11 crashes) to 36.8 percent (7 crashes) for the control segments of Interstate roadway.

Drivers

Driver sex and age were investigated and it was found that no before/after relationship existed regarding sex. Contrary to behaviors observed for Interstate segments, it was not apparent that drivers over the age of 50 on primary roads benefited directly from rumble strip implementation (see Figure 14). During the before period, 18.2 percent (6 crashes) of all off-road crashes involved drivers over the age of 50. Once rumble strips were in place that number rose to 25.0 percent (7 crashes), although as a result of just one more crash. For the off-road primary control segments, 14.3 percent (7 crashes) of drivers were over the age of 50 during the before period, and 17.9 percent (10 crashes) after. Drivers under the age of 21 did not appear to realize a significant benefit from rumble strip implementation on primary roads either.

Vehicle Type

With such a small sample of crash data available for primary roadway crash analysis, vehicle type could not adequately be investigated.

Contributing Circumstance

For primary off-road crashes, it was found that during the before period, inattentive driving was a contributing circumstance for 33.3 percent (11 crashes)

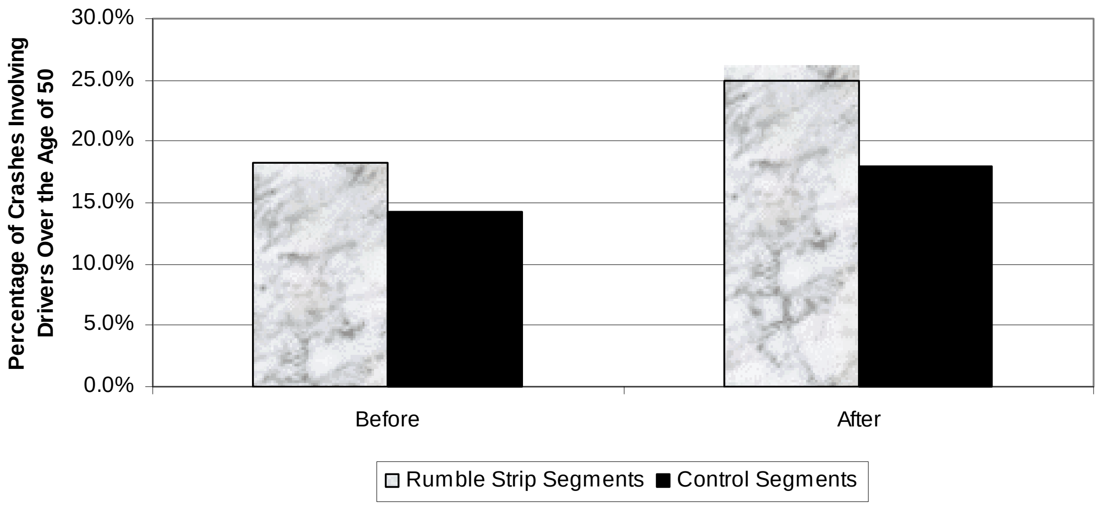


Figure 14. Global Off-road Primary Crashes Involving Drivers Over the Age of 50

of all crashes (see Figure 15). After rumble strips were installed however, that percentage dropped to just 10.7 percent (3 crashes). Conversely, control segments of primary roadway experienced very limited improvement over the same period of time, strengthening the theory that rumble strips aid inattentive drivers in avoiding incidents. Nearly identical relationships were evident for rollover crashes as well, with a dramatic reduction in the number of crashes caused by inattentive driving realized across the before and after analysis periods for the rumble strip segments, but not for the control. "Falling asleep" was listed as a contributing circumstance on 18.2 percent (6 crashes) of all primary off-road crashes for the rumble strip segments of roadway prior to rumble strip implementation (see Figure 15). During the after period, that number rose to 25.0 percent (7 crashes), although the magnitude of crashes changed very little. For the control segments, falling asleep comprised 20.4 percent (10 crashes) beforehand and 16.1 percent (9 crashes) after. The percentages might indicate that rumble strips failed in reducing crashes for drivers that had fallen asleep, yet the numbers themselves prove to reveal very little difference through rumble strip implementation. Similar patterns were found regarding rollover crashes before and after rumble strip implementation. A lack of data relegated further discussion therein fruitless.

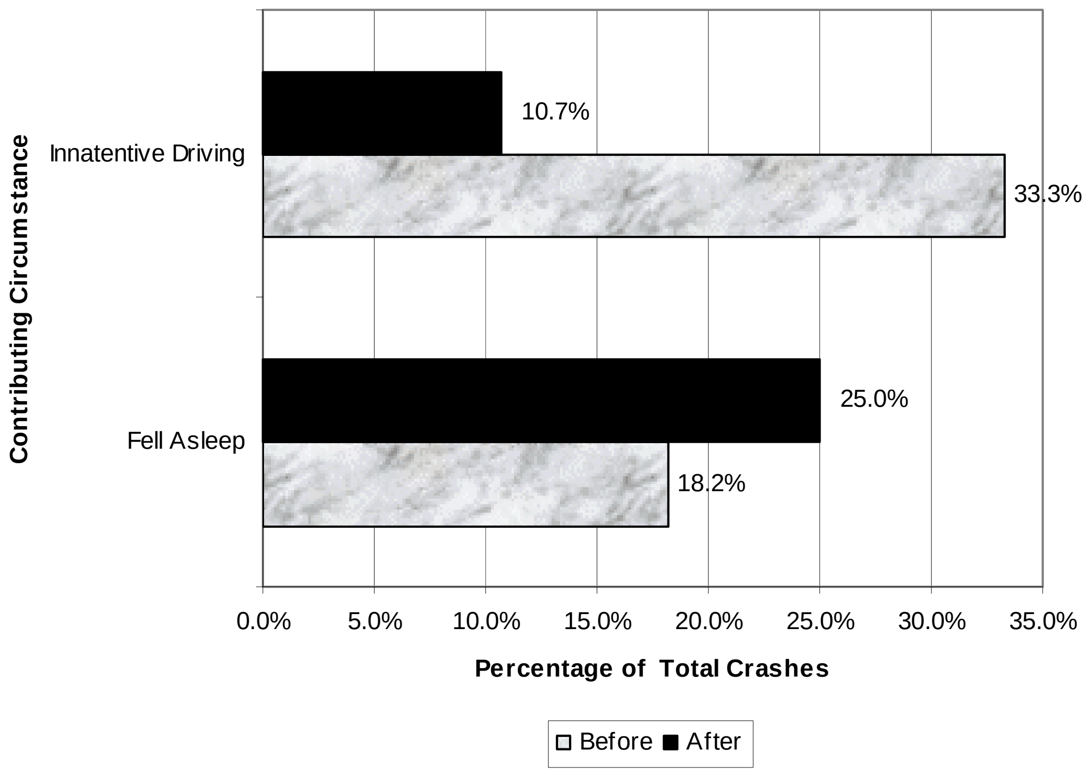


Figure 15. Percentage of Global Off-road Primary Crashes by Contributing Circumstance

Traffic Volumes

The investigation of pre-treatment crash and severity rates as a function of weighted-average Annual Average Daily Traffic (AADT) again proved inconsequential. No relationships could be found for either crash rate or crash severity using the global off-road segment of data from this investigation (see Figure 16). Again, although in both cases it appears that linearly declining trends are evident, the R^2 values indicate that very little of the response variabilities are explained through those approximations.

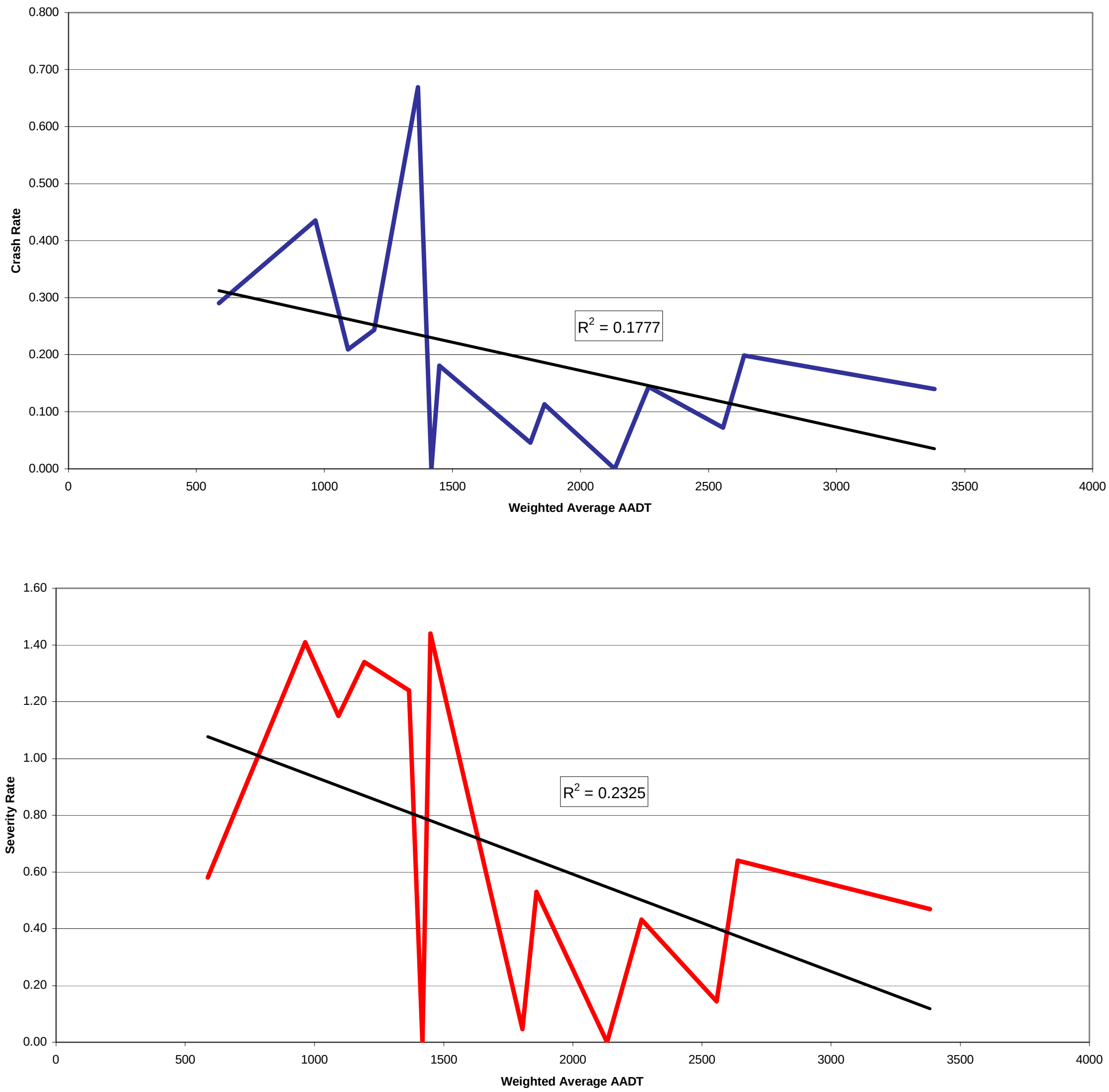


Figure 16. Global Before Period Primary Off-road Crash and Severity Rates vs. Weighted Average AADT

Comparative Statistics Using Segment Data

The comparative relationships investigated for segments of Interstate data were also applied to data for analysis of primary segments in an identical manner.

Crash Frequency and Severity Rates

Crash Frequency and severity rates broken down by primary highway route for off-road and rollover crashes on a 4-mile segment scale can be found in Tables 12 and 13.

Four-mile off-road crashes (see Table 12) realized an improvement in crash rate (-26.7%), while severity also lessened (-18.9%) slightly from the before to after period for 14 primary rumble strip segments. Corresponding control segments witnessed a decrease in crash rate of just 3.3 percent, while severity rates were reduced by 13.9%. In the case of crash rate, a marked relative improvement from the before to after period indicates that rumble strips may have been a positive influence in making the primary roadways in this study safer regarding off-road crash occurrence, if not severity.

The rollover crash analysis results for the primary study segment were negative (see Table 13). Average crash and severity rates both increased, by 19.4 percent and 45.8 percent respectively. The corresponding control segment showed a net decrease in crash rate of 19.3 percent and a 27.3 percent improvement in severity. However, the sample data for rollover crashes is so small that any inferences concerning these statistics would be invalid.

Rumble Strip Segments: Before vs. After Crashes, Crash Rates and Severity Rates

Hypothesis testing of before and after crash data was completed for rumble strip segments on primary roadways broken into four-mile segments. As before, the null hypothesis for each case stated that the number of crashes, crash rate, or severity rate, prior to treatment, would be statistically equal to that after treatment

Table 12. 4-mile Off-road Primary Crash Summary

Primary Routes (# of Segments)		Rumble Strip Segments		Control Segments	
		Avg. Crash Rate	Avg. Severity Rate	Avg. Crash Rate	Avg. Severity Rate
P-1 (4)	Before	0.080	0.438	0.135	0.269
	After	0.221	1.018	0.117	0.287
% Change		**176.3%**	**132.4%**	**-13.3%**	**6.7%**
P-20 (2)	Before	0.148	0.592	0.363	0.997
	After	0.000	0.000	0.450	0.600
% Change		**-100.0%**	**-100.0%**	**24.0%**	**-39.8%**
P-22 (3)	Before	0.435	1.738	0.710	3.018
	After	0.375	2.102	0.556	2.226
% Change		**-13.8%**	**20.9%**	**-21.7%**	**-26.2%**
P-49 (1)	Before	0.501	1.170	0.849	1.529
	After	0.263	0.525	0.795	2.518
% Change		**-47.5%**	**-55.1%**	**-6.4%**	**64.7%**
P-57 (5)	Before	0.075	0.349	0.225	1.102
	After	0.067	0.067	0.194	0.736
% Change		**-10.7%**	**-80.8%**	**-13.8%**	**-33.2%**
P-60 (3)	Before	0.200	0.651	0.295	0.591
	After	0.135	0.853	0.394	0.788
% Change		**-32.5%**	**31.0%**	**33.6%**	**33.3%**
Primary Totals (18)	Before	0.165	0.639	0.244	0.760
	After	0.121	0.518	0.236	0.654
% Change		**-26.7%**	**-18.9%**	**-3.3%**	**-13.9%**

Table 13. 4-mile Rollover Primary Crash Summary

Primary Routes (# of Segments)		Rumble Strip Segments		Control Segments	
		Avg. Crash Rate	Avg. Severity Rate	Avg. Crash Rate	Avg. Severity Rate
P-1 (4)	Before	0.080	0.438	0.000	0.000
	After	0.177	0.974	0.013	0.104
% Change		**121.3%**	**122.4%**	**Infinite**	**Infinite**
P-20 (2)	Before	0.000	0.000	0.091	0.091
	After	0.000	0.000	0.075	0.075
% Change		**0.0%**	**0.0%**	**-17.6%**	**-17.6%**
P-22 (3)	Before	0.072	0.217	0.533	2.485
	After	0.075	0.601	0.371	0.742
% Change		**4.2%**	**177.0%**	**-30.4%**	**-70.1%**
P-49 (1)	Before	0.501	1.171	0.679	2.378
	After	0.131	0.131	0.795	2.518
% Change		**-73.9%**	**-88.8%**	**17.1%**	**5.9%**
P-57 (5)	Before	0.025	0.075	0.112	0.630
	After	0.045	0.045	0.078	0.329
% Change		**80.0%**	**-40.0%**	**-30.4%**	**-47.8%**
P-60 (3)	Before	0.100	0.551	0.222	0.369
	After	0.135	0.853	0.066	0.197
% Change		**35.0%**	**54.8%**	**-70.3%**	**-46.6%**
Primary Totals (18)	Before	0.062	0.240	0.109	0.421
	After	0.074	0.350	0.088	0.306
% Change		**19.4%**	**45.8%**	**-19.3%**	**-27.3%**

at the 95 percent confidence level. A two-sided test allowed for the possibility that rejection of the null hypothesis may result from either a significant increase or decrease in crashes between the before and after periods. In the end, not a single relationship was found to be statistically significant for 4-mile primary segments (see Table 14), indicating that, from a statistical standpoint, rumble strips had no appreciable impact on crash frequency or severity for primary roadways.

Table 14. 4-mile Primary Rumble Strip Segment Before vs. After Paired t-test Results

	Off-road Crashes			Rollover Crashes		
	95% C.I.	t statistic	2-tailed P	95% C.I.	t statistic	2-tailed P
# of Crashes	-0.352 to 0.685	0.68	0.507	-0.522 to 0.411	-0.25	0.805
Crash Rate	-0.071 to 0.111	0.46	0.650	-0.086 to 0.076	-0.13	0.901
Severity Rate	-0.738 to 0.494	-0.42	0.682	-0.672 to 0.267	-0.91	0.376

Rejection Level (t) = + / - 2.101
α = 0.05

Control Segments: Before vs. After Crashes, Crash Rates and Severity Rates

An investigation of before and after relationships for the control roadway segments produced similar results (see Table 15). No statistically significant relationships were evident at a 95 percent level of confidence. This again implies that no statistically substantial change was evident from the before to after period for the control segment of primary roadway data.

Table 15. 4-mile Primary Control Segment Before vs. After Paired t-test Results

	Off-road Crashes			Rollover Crashes		
	95% C.I.	t statistic	2-tailed P	95% C.I.	t statistic	2-tailed P
# of Crashes	-1.225 to 0.780	-0.47	0.646	-0.571 to 0.682	0.19	0.854
Crash Rate	-0.224 to 0.267	0.18	0.856	-0.184 to 0.238	0.27	0.790
Severity Rate	-0.514 to 0.813	0.47	0.641	-0.465 to 1.078	0.84	0.414

Rejection Level (t) = + / - 2.101
α = 0.05

Rumble Strip Segment vs. Control Segment Significance Testing

Contingency table analysis regarding primary highway segments provided consistent and contradictory relationships between rumble strip and control segments, for off-road crashes in general, and for rollover crashes specifically (see Table 16). Off-road crashes as a whole, organized into 4-mile segments, showed a 24.2 percent relative decrease in rate of occurrence, post-treatment, whereas rollover crash rates showed a 47.8 percent relative increase. Neither change was found significant from a statistical standpoint.

Changes in severity rate were found to be minor (-5.8%) for off-road crashes and also lacked significance. For rollover crashes, analyses revealed an apparent relative increase in severity of 100.6 percent, a figure that was found to be statistically significant at a 95 percent confidence interval. Again, lack of sufficient sample data would tend to negate this conclusion.

Table 16. 4-mile Primary Rumble Strip vs. Control Segment Contingency Table Results

	Off-road Crashes			Rollover Crashes		
	χ^2 statistic	p	E (% relative difference)	χ^2 statistic	p	E (% relative difference)
# of Crashes	0.21	0.6488	-22.3%	0.00	1.0000	17.3%
Crash Rate	3.12	0.0774	-24.2%	2.68	0.1017	47.8%
Severity Rate	0.50	0.4776	-5.8%	***38.00***	***< 0.0001***	***100.6%***

Rejection Level (χ^2) = 3.841 (p = 0.05)
α = 0.05

Decreasing trends in crash rate and crash severity for off-road crashes in general, when examined along with their rollover trend counterparts, indicate that the presence of rumble strips may have some effect on the occurrence of rollover type crashes on primary highways. Other factors, such as the change in speed limits from the before to after periods, may have also play a substantial role in severity of crashes. Results of this analysis must be tempered by the fact that the total number of rollover crashes on primary type highways within this study is too small to be considered a valid sample of the total population. Future evaluations of shoulder rumble strips on non-interstate roadways should be considered when total miles of treated highway provides a viable database.

ANALYSIS CONCLUSIONS

The evaluation of rumble strip performance in the state of Montana has proven to be challenging due to the many variables and limitations involved. Any conclusions based on statistical analyses required careful consideration of all elements involved, as well as introspective evaluations, due to the circumstantial nature of the data and the analysis process. Portions of this evaluation may have been further weakened by the fact that a very limited sample of data was available for the analysis of certain subsets of primary highway crash data. However, there are a number of valid and important conclusions that were made as a result of exercise.

In the cases of both Interstate and primary highways, rumble strips appeared to lessen the number of crashes occurring during hours of darkness. It follows that through times of compromised visibility, the ability of rumble strips to offer a warning that appeals to senses other than sight would decrease the probability of being involved in an off-road crash.

Rumble strips also may have contributed in reducing the number of crashes experienced by drivers over the age of 50, yet seemingly only on Interstate roadways. No significant benefits were evident regarding primary roadways with regard to age. Similar behaviors were evident for young drivers, under the age of 21, who as a group appeared to benefit from rumble strip implementation on Interstates but once again not on primary roadways. The supposed differences from Interstate highways likely stem from the simple fact that primaries often have smaller shoulders than do Interstates. In certain cases, rumble strips may act only as a harbinger of an impending crash. Such a situation is much more likely to arise where less shoulder area is available for recovery.

Limited study data indicates that there is a possibility that motorcycles may be impacted by rumble strip installation, based upon unexplained trends seen in the Interstate data analyzed within this study. There is no reliable statistical evidence to prove or disprove any connection between rumble strips and motorcycle. However, the observations are noteworthy as a subject for future research.

No conclusion could be made regarding rumble strips and bicycles since there were no records of bicycle accidents on any of the study segments. Additional effort was expended to locate bicycle accidents on highway segments that were not included in the final study, to no avail.

The investigation of contributing circumstance produced generally expected results. The percentages of Interstate crashes attributed to inattentive driving and falling asleep while driving each fell by a considerable margin, apparently through rumble strip implementation. The results for primary roadways were very similar as far as inattentive driving crashes were concerned. However, the prevention of crashes caused by drivers falling asleep did not appear to benefit directly through the use of rumble strips on primary roads, yet a limitation on available data clouded such judgment. One of many possibilities open to future research is the theory that shoulder rumble strips may, at times, have the effect of “scaring” sleeping drivers to the extent that reflexive over-correction may result.

Roadway widths were investigated for primary highways due to their high variability on such roads throughout the state of Montana. Crash rates before and after rumble strip implementation did not show any appreciable dependence upon roadway widths, while behaviors regarding severity were found to contradict intuition without explanation.

Comparative analyses revealed a number of informative, if not statistically significant, relationships regarding Interstate rumble strip usage. A before vs. after analysis showed that, from a statistical standpoint, crash and severity rates have not changed significantly for either the Interstate rumble strip or control sections as a result of rumble strip implementation. A second statistical procedure showed statistical significance only for the relative difference in off-road crash severity between the before and after period trends for rumble strip and control sections. However, through the use of simple percent difference analysis it was apparent that for the Interstate highways included in this study, off-road crash rates and severities were reduced through the implementation of shoulder rumble strip technology. An extension of the contingency table procedure provided relative improvements in off-road crash and severity rates of 14.0 and 23.5 percent, respectively. The isolation of rollover accidents specifically, showed less benefit from should rumble strip treatment as a whole, revealing only a slight improvement in crash rate (5.5% improvement) and no substantial difference (2.7% deterioration) in severity.

An analysis of before and after crash rates and severities on primary sections of roadway also proved fruitless from a statistical standpoint, revealing no significant changes in behavior as a result of paired t-testing, for either off-road accidents in general or rollover accidents specifically. However, the comparison of primary control and treatment sections did yield a significant difference regarding the changes in severity rate for rollover accidents. Relative calculated increases for both crash rate (47.8%) and crash severity (100.6%) in the case of primary rollover accidents were realized. On the other hand, relative decreases in both crash rate (24.2%) and severity (5.8%) were apparent regarding off-road crashes in general for primary roadways. Again, lack of an adequate database sample for primary roadways severely weakens any conclusions that may be drawn from this analysis.

As a whole, rumble strips seem to be moderately successful in reducing the occurrence of various situational crashes, most notably those caused by falling asleep at the wheel or through inattentive driving. As they pertain to the roadway systems themselves, the effect of shoulder rumble strips on crash experience was not statistically significant at the confidence level investigated. In fact, while Interstate and primary system analyses showed some benefit for off-road crash rate and severity in certain situations, an investigation of rumble strip performance for rollover crashes specifically showed that crash severity may well have increased through rumble strip deployment or other undefined factors. No specific rationale for determining the reason behind this increase is evident. As a result, further investigation may be warranted.

SHOULDER RUMBLE STRIP SURVEY

Objectives

Initially, the research study plan included a study element that would document relative frequency of rumble strip encounters and determine drivers' reaction to the encounters by means of video surveillance. In detailing the scope of work for this portion of the project, it became apparent that no off-the-shelf technology existed. Even though it was technically possible to assemble electronic actuation devices, recording systems, and the structural framework of a recording station, the cost of implementing and reducing data appeared to be prohibitive. Since the relative value of this effort was also unknown, an alternate means of accomplishing similar objectives was proposed and accepted by the research committee.

A road users' survey of shoulder rumble strips was used to determine the general public's experience with and attitude toward rumble strips. Specific objectives of the survey were:

1. Drivers' knowledge: To ascertain what percentage of drivers know what rumble strips are and what they are used for.

2. Relative exposure rate: To determine how often the average driver runs over rumble strips.

3. Reactions: To determine drivers' initial reactions to encounters with rumble strips.

4. Incident avoidance: To determine the perceived effectiveness of rumble strips in terms of crash prevention.

5. Overall public attitude: To discover how the public perceives shoulder rumble strips and determine the general attitude towards them (like, dislike, apathy).

Survey Sites & Questions

Surveys were taken at four separate rest areas in Montana. Three of the survey sites were located on the Interstate system and one was on a primary highway. The sites were selected based on location, knowledge of facilities, and potential usage. A listing of those sites is as follows:

Interstate:	Quartz Flats, I-90 northwest of Missoula
	Dearborn, I-15 south of Great Falls
	Bozeman, I-90 in Bozeman
Primary:	Bridger, P-4 (US 310) north of Bridger

Surveys were conducted in August and September of 2001. The questionnaire form consisted of 9 questions, which were designed to determine the study objectives. Those questions were generally as follows:

1. Are you familiar with highway shoulder rumble strips?
2. Have you ever run over a shoulder rumble strip?
3. How often does this happen?
4. What was the cause or causes for driving over the shoulder rumble strip or strips?
5. What was your reaction the first time you ran over one?
6. During the past year, how many miles have you driven on Montana Highways?
7. What type of vehicle do you normally drive?
8. What is your general opinion of shoulder rumble strips?
9. Do you have any additional comments or suggestions regarding shoulder rumble strips?

Survey Results & Relevance to Crash Statistics

A total of 337 completed questionnaires were collected from the four survey sites. Of those responding to the survey, 64 percent were male and 60 percent were from a state other than Montana. Eighty-four percent of the respondents were between the ages of 25 and 55 years of age. Descriptive and relational statistics were evaluated and a separate report was prepared, which detailed survey methods and provided statistical summaries for all aspects of the users' survey. The following statistics were extracted from that report and are presented in relation to the crash statistics summarized within this report.

1. Knowledge of Shoulder Rumble Strips -- Only 5 people or 1 percent of all respondents did not know what shoulder rumble strips were. This establishes the fact that the vast majority of the traveling public has at least a rudimentary knowledge of the device and its intended purpose.

2. Experience with Shoulder Rumble Strips – Ninety-five percent of all respondents indicated that they have encountered rumble strips at least once. This confirms that almost all motorists have had first hand experiences with rumble strips and are familiar with the associated sounds and sensations.

3. Frequency – Fifty-six percent claimed that they very seldom hit rumble strips when traveling. Twenty-five percent indicated that they hit rumble strips on every, or every other highway-type trip, while twelve percent hit them more than once each trip. This statistic indicates that encounters with rumble strips are somewhat common, yet also somewhat rare, in terms of total vehicle miles driven.

4. Cause – The survey allowed more than one choice from a list of eight possible answers. Fifty percent of the respondents indicated that they had hit rumble strips when their vehicle drifted off course. This was the most common choice of the eight available. The second highest was "being distracted", which was marked by 44 percent of the respondents. The average of these two responses (47%) can be compared to the following study crash report summaries for “inattentive driving” as a contributing circumstance:

Interstate

Inattentive Driving:	Before	After	Decrease
Rumble Strip Segments	31%	19%	12%
Control Segments	30%	21%	9%

Primary Inattentive Driving:	Before	After	Decrease
Rumble Strip Segments	33%	15%	12%
Control Segments	27%	25%	2%

It cannot be stated with any certainty that drivers who claimed their vehicle drifted or that they had been were inattentive could be considered “inattentive”, yet it appears that both would be solid characteristics of inattentive driving behavior. In this case, there is strong evidence that rumble strips have alerted drivers of impending danger and have possibly avoided crash incidents. Crash data does not provide this evidence as clearly as the survey. There are numerous factors involved in crash avoidance that are unaccountable and it would appear from the survey that shoulder rumble strips are perceived as an important one.

Most other popular choices in the survey dealt with intentional vehicular maneuvers except for “fell asleep”. Only 9 percent of all respondents chose this reason for hitting rumble strips. This value can be compared to the following study crash report summaries for “fell asleep” as a contributing circumstance:

Interstate Fell Asleep:	Before	After	Decrease
Rumble Strip Segments	31%	23%	8%
Control Segments	25%	27%	-2%

Primary Fell Asleep:	Before	After	Decrease
Rumble Strip Segments	18%	25%	-7%
Control Segments	20%	16%	4%

The reliability of this survey statistic appears to be biased downward due to the fact that many respondents openly stated that they would not want to admit to falling asleep while driving. Respondents who did choose this as a causative factor were very candid in their reply and several claimed that the rumble strip undoubtedly prevented a crash by awakening them. Falling asleep on Interstate segments was a major factor in off-road crashes and coincidentally, the reduction in crashes after the installation of rumble strips was very near the 9 percent level. It is interesting to note that crash experience on two-lane primary highways would appear to have the opposite effect from the Interstate segments. The response to this question at the Bridger Rest Area (primary highway) was made slightly less than 7 percent of the time, but does little to explain the inverse relationship. Vehicle dynamics and the driver's mindset, while driving on two lane roadways, are potential explanations for an increase in "fell asleep" crashes. The immediate reaction to being awakened by rumble strips on a two-lane roadway may either be over-correction to the left-hand ditch to avoid on-coming traffic, or some other maneuver equally as critical.

5. Reaction - Forty-five percent of respondents indicated that they became more alert, while twenty-six percent said they steered back into the travel lane. An equal number of people (7%) indicated that they awoke or had no reaction. Only four percent indicated that they had steered sharply away from the rumble strips and no one claimed to have lost control of their vehicle. The most popular answer, "became more alert", would be the political correct answer, and the second most popular answer, "steered back into the travel lane", the most generic. Only thirteen percent of the respondents chose an answer that implied shock or surprise, which resulted in actions other than normal driving behavior. If these answers could be judged candidly, it would appear that rumble strips would have minimal if any involvement in creating crash situations.

6. Exposure – Seventy-one percent of the respondents drove less than 5,000 miles per year on Montana highways and only fifteen percent drove over 10,000 miles. These answers don't provide a true exposure rate since sixty percent of the respondents were from out of state and many of them were driving Montana's highways for the first time. Calculations based on this question indicate that the weighted average number of miles driven on Montana highways would be 2,400 for each respondent. If the average trip length were 200 miles, each respondent would make 12 trips per year. Combined with the results of question number 3 regarding frequency of rumble strip encounters, where the average number of encounters is calculated to be 0.6 per trip, the average respondent would encounter (hit) rumble strips 7.2 times per year. This translates into 0.003 encounters per mile for the average respondent. On a facility carrying 5,000 AADT, rumble strips would be hit 15 times per mile per day. While these calculations are an over-simplification of the exposure rate, they serve to indicate that motorists' exposure to rumble strips are substantial on a system-wide basis.

7. Vehicle Type – This question was designed to determine how the mix of vehicles in the survey's general population compares to the mix of vehicles involved in off-road crashes. The mix of vehicles listed on the survey form, and the corresponding percentages of respondents' vehicles listed in crash reports are presented in Table 17. Passenger cars comprise a substantially smaller portion of the rest area survey mix than does the corresponding involvement in off-road crashes. The opposite is true for vans, SUVs, and RVs. There were no bicycles encountered during the rest area surveys and none of the motorcyclists encountered (estimated at 2% of all vehicles) were willing to participate in the survey.

8. Opinions - Survey respondents overwhelmingly favored the use of rumble strips, with fifty-five percent checking the "like them very much" box, and thirty six percent checking the "like them" box. Only two percent of all respondents disapproved of rumble strips to varying degrees. This further supports the fact that the traveling public is aware of their use and intended purpose.

Vehicle Type	Survey %	Interstate* Before Crash %	Interstate* After Crash %	Primary* Before Crash %	Primary* After Crash %
Passenger Car	37%	57%	53%	52%	39%
Pick-up Truck	23%	24%	16%	27%	39%
Van or Mini-van	14%	3%	5%	0%	0%
Sport Utility Vehicle	11%	0%	8%	0%	4%
RV or Vehicle with Trailer	7%	1%	1%	3%	0%
Commercial Tractor-trailer	7%	13%	12%	3%	0%
Other Vehicle	1%	2%	5%	15%	18%

* Crash Data For Rumble Strip Study Segments Before & After Installations

Table 17. Comparison of Survey Vehicle Types with Crash Vehicle Types

9. Comments – Various comments were recorded on the survey sheets and the majority of comments reinforced the public's desire for continued use of rumble strips and expansion of their use to all roads.

BENEFIT/COST ANALYSIS

The Montana Department of Transportation Safety Engineering Improvement Program includes a documented procedure for the computation of the annual benefit/cost ratio of projects. The benefit side of this ratio is based on the concept that the total economic loss as a result of crashes is determined by the severity of injuries and the number of crashes, and that specific improvements will yield reductions in crash costs. Concepts of this computation on the cost side of the ratio relate to the cost of construction, maintenance, and operations.

Due to the limited sample size and the variables involved, the benefit/cost analysis ratio was not calculated for the primary highway routes.

Benefits

In the Safety Engineering Improvement Program, fatal and injury crash benefits calculations are combined into a single quotient called "Q." This complies with FHWA Technical Advisory T7570.1 (June 30, 1998), *Recommended Accident Costs*. The ratio of injuries to fatalities varies depending on the class of facility. The 2001 Q factor for Montana Rural Interstates was $169,320.00.

The planned annual benefit (in dollars) is expressed by the equation:

$$Q\ (Afi)\ Pfi + Cpd\ (Apd)\ Ppd$$

Where:

Q	=	average cost per fatality and injury combined
Afi	=	average number of annual fatalities and injuries combined
Pfi	=	expected percent reduction in fatalities and injuries
Apd	=	average annual property-damage-only crashes
Cpd	=	cost per property-damage-only accidents
Ppd	=	expected percent reduction in property-damage-only accidents

To account for changes in traffic volumes over the expected life of the project, the above formula is multiplied by the ratio of average daily traffic (ADT) after improvements to before as follows:

$$\frac{ADT_A}{ADT_B} = \frac{(1.03)^L + 1}{(1.03)^{-S} + 1}$$

Where: L = number of years for the life of the project

S = number of years of crash records used in the analysis

Benefits of rumble strips installations were calculated based on the rumble strip segments within this study and the crash reduction experienced. To determine variables in the benefit equation, control data from the global Interstate rumble strip study base was used, as follows:

Parameter		Value
Miles	=	196.7
Off-Road Crashes	=	327
Years	=	3
PDO Crashes	=	153 (46.8%)
Fatal & Injury Crashes	=	174 (53.2%)
Fatalities & Injuries	=	257
Off-road Crashes per mile per year	=	0.554
Off-road PDO Crashes per mile per year (Apd)	=	0.259
Off-road Fatalities & Injuries per mile per year (Afi)	=	0.436
Calculated Relative Accident Reduction Percentage	=	13.9%

The ADT factor (ADT_A/ADT_B) is calculated to be 1.224 based on a 10 year design life of rumble strips and a 3 percent annual traffic growth factor.

Other factors in the benefit equation are computed to be:

Q	=	\$169,320
Afi	=	257/3 = 85.66
Pfi	=	13.4% (Table 9, page 41)
Apd	=	153/3 = 51.00
Cpd	=	\$4,500
Ppd	=	13.4% (Table 9, page 41)

The benefit calculation for the Interstate Routes segments is:

$$B = 1.224\ [169320(85.66)0.134+4500(51.00)0.134] = \mathbf{\$2{,}416{,}522}$$

Costs

Costs for installation of rumble strips have been reduced over the past 5 years due to improved technology and availability of alternate installation equipment. Rumble strip gaps of 12’ in a 60’ cycle have also contributed to reduced costs per mile. The year 2001 MDT Unit Price Summary for shoulder rumble strips was reported at \$286.48 per kilometer or \$461.00 per linear mile. Installation costs on Interstates would be \$1,844.00 per mile of roadway. With the costs of mobilization, traffic control, and contingencies at 45 percent, the construction costs reach \$2673.80 per mile of roadway. Maintenance of rumble strips would include occasional sweeping to remove sand and some replacement after spot patching. Maintenance costs were estimated at approximately 10% of installation costs on an annual basis, which would be \$267.38 on Interstate routes.

The annual costs associated with shoulder rumble strips were calculated on the basis of a 10 year design life at a discount rate of 6%, which is approximately the current FHWA rate for benefit/cost analysis. The K factor for capitol recovery at 6% for 10 years is 0.1358 and annual costs are as follows:

Interstate Costs: [2674 x 0.1358 + $267] x 196.7 = **$123,946**

Benefit/Cost Ratio

The benefit cost ratio is calculated by dividing annual benefits by annual costs. The following B/C ratio is a result of those calculations:

Interstate B/C = 19.5

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APPENDIX

Tables A-1 thru A-10

TABLE A-1. LIST OF RUMBLE STRIP PROJECTS & CONSTRUCTIONS DATES

Route Number	Project Number	Project Name	Begin Date	End Date	From Mile Post	To Mile Post	Total Length	Proj Type
I-15	IM 15-1 (85) 0	MONIDA - LIMA BEAVERHEAD COUNTY	05/04/95	10/16/96	0.00	17.98	17.98	
I-15	IM 15-1 (87) 64	DILLON - APEX	02/10/98	12/09/99	64.00	75.30	11.30	
I-15	IM 15-1 (86) 74	APEX - GLEN	02/10/98	12/09/99	74.00	85.18	11.18	
I-15	IM 15-1 88) 86	GLEN - MELROSE	06/11/98	08/10/99	86.00	93.78	7.78	
I-15	IM 15-4 (81) 195	HELENA - NORTH	10/10/96	12/19/97	195.00	202.33	7.33	
I-15	IM 15-4 (75) 200	LINCOLN ROAD - SIEBEN	08/31/95	07/29/97	200.00	217.09	17.09	
I-15	IM 0002(222) [2991]	DISTRICT 3	02/07/96	08/02/96	216.50	240.00	23.50	
I-15	IM 0002(222) [2991]	DISTRICT 3	02/07/96	08/02/96	240.00	247.80	7.80	
I-15	IM 15-5 (90) 248	HARDY CREEK - ULM (SOUTHBOUND)	10/10/96	11/07/97	248.00	269.85	21.85	
I-15	IM 15-5 (93) 256	HARDY CREEK - ULM (NORTHBOUND)	09/04/97	06/19/99	256.00	270.17	14.17	
I-15	IM 0002(222) [2991]	DISTRICT 3	02/07/96	08/02/96	270.40	301.40	31.00	
I-15	STPI 15-5 (94) 283	GREAT FALLS - VAUGN	11/07/97	07/19/99	283.00	296.42	13.42	
I-15	IM 0002(222) [2991]	DISTRICT 3	02/07/96	08/02/96	309.70	322.30	12.60	
I-15	IM 15-6 (28) 323 F	BRADY - NORTH & SOUTH (NB)	04/06/95	06/24/97	323.00	334.57	11.57	
I-15	IM 0002(222) [2991]	DISTRICT 3	02/07/96	08/02/96	334.30	343.30	9.00	
I-15	IR 15-8(47) 354	SHELBY - SOUTH - TOOLE COUNTY	02/04/92	08/25/94	354.00	365.00	11.00	
I-15	STPI 15-8 (51) 380	KEVIN - SUNBURST	11/21/97	06/23/99	380.00	394.84	14.84	
I-90	IM 90-1 (118) 64	TARKIO - EAST	03/07/96	11/03/97	64.00	74.05	10.05	
I-90	IM 90-1 (119) 74	ALBERTON - EAST & WEST	11/21/97	10/28/98	74.00	89.52	15.52	
I-90	IM 90-2 (93) 84	FRENCHTOWN - EAST & WEST	06/05/95	09/27/96	84.00	94.16	10.16	
I-90	IM IR 90-2(90)119	CLINTON - EAST & WEST	11/16/93	11/04/94	119.00	134.00	15.00	
I-90	IM 90-3 (74) 135	BEARMOUTH - DRUMMOND	06/29/94	09/18/95	135.00	150.19	15.19	
I-90	IM 90-3 (72) 189	DEERLODGE - SOUTH	06/03/94	07/27/95	189.00	194.36	5.36	
I-90	IM 0002 (304)	DISTRICT 3	12/07/92	07/08/94	278.80	289.30	10.50	<
I-90	IM 90-6 (68) 279	THREE FORKS - MANHATTAN	06/03/93	05/19/95	279.00	289.62	10.62	<
I-90	IM 90-6 (70) 313	ROCKY CANYON - GALLATIN COUNTY	06/05/95	07/10/96	313.00	318.16	5.16	
I-90	IM 90-6(63) 318	BOZEMAN HILL - EAST & WEST	06/03/93	07/28/94	318.00	330.00	12.00	<
I-90	IM 0002 (304)	DISTRICT 3	12/07/92	07/08/94	318.30	330.80	12.50	<
I-90	IM 90-8 (131) 450	27TH - LOCKWOOD	05/02/96	04/27/98	450.00	453.61	3.61	
I-90	IM 90-9 (81) 503 F	DUNMORE - SOUTH	10/12/95	05/03/97	503.00	512.33	9.33	
I-94	STPI 94-1 (54) 0	BILLINGS - HUNTLEY	11/07/97	10/20/98	1.18	12.28	11.10	
I-94	IM 0002(58) [2379]	DISTRICT 4 INTERSTATE RUMBLE STRIPS	12/16/93	09/06/94	103.90	128.30	24.40	<
I-94	IM 94-3 (50) 115	5.3 KM WEST OF HATHAWAY - EAST	10/07/97	10/15/98	115.00	137.97	22.97	<
I-94	IM 94-4(48) 129	MILES CITY - WEST CUSTER COUNTY	03/05/93	06/30/94	129.00	137.00	8.00	<
I-94	IM 94-9 (49) 154	CUSTER COUNTY LINE - WEST	03/07/96	07/18/97	154.00	162.86	8.86	
I-94	IM 94-5 (27) 163	PRARIE COUNTY LINE - EAST	02/11/97	09/24/98	163.00	173.17	10.17	
I-94	IM 0002(58) [2379]	DISTRICT 4 INTERSTATE RUMBLE STRIPS	12/16/93	09/06/94	184.50	191.30	6.80	
I-94	IM 94-6 (41) 191	DAWSON COUNTY LINE - EAST	10/14/94	11/10/95	191.00	209.79	18.79	
I-94	IM 0002(58) [2379]	DISTRICT 4 INTERSTATE RUMBLE STRIPS	12/16/93	09/06/94	217.90	243.70	25.80	
	Interstate Total						**515.31**	
P-1	STPP 1-2 (42) 125	KALISPELL - NORTHEAST	04/07/94	07/07/95	125.00	129.57	4.57	REC
P-1	NH 1-3 (34) 210 F	TWO MEDICINE BRIDGE - EAST	05/06/97	10/15/98	210.00	222.77	12.77	RE
P-1	NH 1-3 (27) 219 F	BROWNING - EAST & WEST	10/12/95	09/14/98	219.00	225.34	6.34	REC
P-1	STPHS 0002(271)	DISTRICT 3 & 5	10/10/96	08/14/97	423.90	428.50	4.60	RU
P-1	STPHS 0002(271)	DISTRICT 3 & 5	10/10/96	08/14/97	429.10	446.00	16.90	RU
P-1	STPHS 0002(112)	DISTRICT 4	12/16/93	09/06/94	446.30	453.70	7.40	RU
P-1	NH 1-8 (20) 472	MALTA - SACO	07/09/96	10/20/97	472.00	499.35	27.35	RE
P-1	STPN 1-9 (34) 508	HINSDALE - EAST & WEST	11/07/97	08/01/98	508.00	520.20	12.20	REC
P-1	STPHS 0002(112)	DISTRICT 4	12/16/93	09/06/94	508.10	515.60	7.50	RU
P-1	NH 1-9 (31) 516	HINSDALE - EAST - VALLEY COUNTY	09/06/95	07/21/97	516.00	525.92	9.92	RE
P-1	STPHS 0002(112)	DISTRICT 4	12/16/93	09/06/94	537.60	540.50	2.90	RU
P-1	NH 1-9 (30) 565	FRAZER - EAST & WEST	05/05/98	10/21/99	565.00	578.24	13.24	REC
P-1	STPHS 0002(112)	DISTRICT 4	12/16/93	09/06/94	611.10	623.10	12.00	RU
P-1	STPHS 0002(112)	DISTRICT 4	12/16/93	09/06/94	656.30	667.10	10.80	RU
P-1	F-HES 1-10(24) 592	PLENTYWOOD - SOUTHEAST	08/08/88	07/29/89	592.00	602.00	10.00	REC
P-10	NH 10-2 (16) 52 F	LOMA - NORTH CHOUTEAU COUNTY	07/30/93	10/20/95	52.00	61.74	9.74	REC
P-13	STPP 13-1 (22) 0	RAYNOLDS PASS - NORTH	10/10/96	08/05/98	0.00	39.17	39.17	RE
P-13	STPP 13-1 (19) 65	NORRIS - HARRISON	04/08/97	08/08/98	65.00	74.84	9.84	REC
P-14	STPN 14-3 (10) 101	HARLOWTON - EAST	11/07/97	07/19/98	101.00	112.71	11.71	RE
P-19	STPP 19-1 (19) 1	ANACONDA - EAST	03/03/94	08/22/95	1.00	10.48	9.48	RE
P-20	STPHS 0002(112)	DISTRICT 4	12/16/93	09/06/94	53.40	62.40	9.00	RU
P-22	STPHS 0002(112)	DISTRICT 4	12/16/93	09/06/94	28.90	31.50	2.60	RU
P-22	STPHS 0002(112)	DISTRICT 4	12/16/93	09/06/94	32.20	49.90	17.70	RU
P-23	NH 23-3 (7) 119	ALZADA - WEST	06/03/97	09/21/99	119.00	129.84	10.84	RE
P-24	NH 24-1(37) 16	POTOMAC EAST - MISSOULA COUNTY	02/04/93	09/19/93	16.00	22.00	6.00	RU
P-24	NH 24-1 (34) 27 F	CLEARWATER JCT. - WEST	11/16/93	08/04/95	27.00	31.98	4.98	REC
P-24	NH-BR 24-4 (12) 138 F	SUN RIVER BRIDGE - SUN RIVER	08/31/95	07/02/97	138.00	139.78	1.78	RE
P-26	BR-STPP-STPE 26-1 (9) 1	YELLOWSTONE RIVER BRIDGE - SE	07/08/93	08/21/95	1.00	1.94	0.94	?
P-3	STPHS 0002(271)	DISTRICT 3 & 5	10/10/96	08/14/97	16.90	23.50	6.60	RU
P-3	STPHS 0002(271)	DISTRICT 3 & 5	10/10/96	08/14/97	24.50	28.00	3.50	RU
P-37	NH 37-3 (9) 77 F	CAMPS PASS - EAST	03/11/98	04/12/00	77.00	89.63	12.63	REC
P-39	RTF 39-1 (24) 24	COLSTRIP - NORTH	12/11/97	07/30/98	24.00	57.61	33.61	RE
P-4	STPN 4-1 (18) 34	FROMBERG - NORTH	11/21/97	07/13/98	34.00	48.90	14.90	RE
P-49	STPP49-1(7)2	DILLON - NORTH	12/07/92	07/08/94	2.00	9.00	7.00	?
P-5	STPN 38-1 (8) 0	WHITEFISH - EAST	11/07/97	08/13/98	0.00	7.04	7.04	RE
P-5	STPN 5-1 (19) 1	DESMET - NORTH	11/07/97	07/30/99	1.00	10.33	9.33	RE
P-5	STPN 5-1 (20) 6	EVARO - NORTH	11/07/97	07/30/99	6.00	20.00	14.00	RE
P-5	NH-PLH 5-3 (61) 115 F	GRANDVIEW - NORTH	04/11/96	11/25/97	115.00	117.08	2.08	REC
P-5	PLH NH 5-3 (62) 123	MONTANA 40 - SOUTH	04/11/96	11/25/97	123.00	126.00	3.00	REC
P-52	STPP 52-2 (24) 33	CRESTON - SOUTH	09/04/96	10/16/98	33.00	40.08	7.08	REC
P-52	STPP 52-2 (20) 40	CRESTON - NORTH	05/04/95	06/16/97	40.00	47.86	7.86	REC
P-53	NH 53-1 (18) 16 F	ACTON - NORTHWEST	07/09/96	07/23/98	16.00	27.50	11.50	REC
P-57	STPHS 0002(271)	DISTRICT 3 & 5	10/10/96	08/14/97	34.40	63.40	29.00	RU
P-6	STPP 6-1 (61) 109	DIXON - RAVALLI	10/07/97	06/11/99	109.00	116.24	7.24	RE
P-60	STPHS 0002(271)	DISTRICT 3 & 5	10/10/96	08/14/97	60.30	71.00	10.70	RU
P-60	STPHS 0002(271)	DISTRICT 3 & 5	10/10/96	08/14/97	81.20	87.00	5.80	RU
P-62	STPN 62-1 (9) 2	CULBERTSON - SOUTH	11/07/97	07/19/99	17.16	19.16	2.00	RE
P-50	STPP 50-2 (25) 82	BOZEMAN - FOUR CORNERS	12/15/94	07/23/97	82.00	88.16	6.16	REC
	Non-interstate Total						**493.27**	

TABLE A-2. STUDY LOCATIONS & CONSTRUCTION PERIODS

INTERSTATE						
		Begin	End	Distance	Construction Dates	
Description	Route	Mile Post	Mile Post	Miles	Begin	End
Interstate 90:						
Rumble Strip Section	I-90	64.0	74.0	10.0	Mar-96	Nov-97
Rumble Strip Section	I-90	89.5	94.2	4.7	Jun-95	Sep-96
Control Section	I-90	105.3	109.7	4.4		
Rumble Strip Section	I-90	119.0	134.0	15.0	Nov-93	Nov-94
Rumble Strip Section	I-90	135.0	150.0	15.0	Jun-94	Sep-95
Control Section	I-90	150.5	178.0	27.5		
Rumble Strip Section	I-90	189.0	194.3	5.3	Jun-94	Jul-95
Control Section	I-90	241.0	248.7	7.7		
Rumble Strip Section	I-90	279.0	287.8	8.8	Dec-92	May-95
Control Section	I-90	307.2	313.0	5.8		
Rumble Strip Section	I-90	313.0	318.0	5.0	Jun-95	Jul-96
Rumble Strip Section	I-90	318.0	330.8	12.8	Dec-92	Jul-94
Control Section	I-90	341.0	353.0	12.0		
Control Section	I-90	369.0	378.0	9.0		
Control Section	I-90	463.0	473.0	10.0		
Control Section	I-90	486.5	495.8	9.3		
Rumble Strip Section	I-90	503.0	512.1	9.1	Oct-95	May-97
I-90 Control Section Total =				85.7		
I-90 Rumble Strip Section Total =				85.7		
I-90 Total Study Miles =				171.4		
Interstate 94:						
Control Section	I-94	23.3	78.3	55.0		
Rumble Strip Section	I-94	154.0	162.0	8.0	Mar-96	Jul-97
Rumble Strip Section	I-94	185.0	191.0	6.0	Dec-93	Sep-94
Rumble Strip Section	I-94	193.0	209.0	16.0	Oct-94	Nov-95
Rumble Strip Section	I-94	218.0	243.0	25.0	Dec-93	Sep-94
I-94 Control Section Total =				55.0		
I-94 Rumble Strip Section Total =				55.0		
I-94 Total Study Miles =				110.0		
Interstate 15:						
Rumble Strip Section	I-15	0.0	17.0	17.0	May-95	Oct-96
Control Section	I-15	17.1	37.9	20.8		
Control Section	I-15	115.9	124.0	8.1		
Control Section	I-15	129.7	142.3	12.6		
Control Section	I-15	175.5	190.0	14.5		
Rumble Strip Section	I-15	197.8	216.5	18.7	Aug-95	Dec-97
Rumble Strip Section	I-15	323.0	334.3	11.3	Apr-95	Jun-97
Rumble Strip Section	I-15	334.3	343.3	9.0	Jul-96	Aug-96
I-15 Control Section Total =				56.0		
I-15 Rumble Strip Section Total =				56.0		
I-15 Total Study Miles =				112.0		
Interstate Control Section Total =				**196.7**		
Interstate Rumble Strip Totals =				**196.7**		
Interstate Study Miles =				**393.4**		

NHS & PRIMARY HIGHWAYS							
		Begin	End	Distance	Construction Dates		Pave
Description	Route	Mile Post	Mile Post	Miles	Begin	End	Width
Primary Route 1:							
Control Section	P-1	129.5	133.5	4.0			68
Rumble Strip Section	P-1	213.0	217.0	4.0	May-97	Oct-98	40
Control Section	P-1	255.0	262.0	7.0			40
Rumble Strip Section	P-1	480.0	487.0	7.0	Jul-96	Oct-97	41
Control Section	P-1	579.0	588.9	9.9			32
Rumble Strip Section	P-1	613.1	623.0	9.9	Dec-93	Sep-94	42
Control Section	P-1	642.0	650.0	8.0			32
Rumble Strip Section	P-1	656.3	664.3	8.0	Dec-93	Sep-94	32
P-1 Control Section Total =				28.9			
P-1 Rumble Strip Section Total =				28.9			
P-1 Total Study Miles =				57.8			
Primary Route 3:							
Control Section	P-3	20.0	23.5	3.5			37
Rumble Strip Section	P-3	24.5	28.0	3.5	Oct-96	Aug-97	35
P-3 Total Study Miles =				7.0			
Primary Route 20:							
Control Section	P-20	6.3	15.0	8.7			40
Rumble Strip Section	P-20	53.4	62.1	8.7	Dec-93	Sep-94	40
P-20 Total Study Miles =				17.4			
Control Section	P-22	11.0	26.0	15.0			20
Rumble Strip Section	P-22	32.2	40.9	8.7	Dec-93	Sep-94	20
Rumble Strip Section	P-22	43.5	49.8	6.3	Dec-93	Sep-94	24
Primary Route 22:							
P-22 Control Section Total =				15.0			
P-22 Rumble Strip Section Total =				15.0			
P-22 Total Study Miles =				30.0			
Primary Route 24:							
Control Section	P-24	2.0	4.8	2.8			40
Rumble Strip Section	P-24	16.2	19.0	2.8	Feb-93	Sep-93	40
P-24 Total Study Miles =				5.6			
Primary Route 49:							
Rumble Strip Section	P-49	2.0	9.0	7.0	Dec-92	Jul-94	24
Control Section	P-49	9.0	16.0	7.0			24
P-49 Total Study Miles =				14.0			
Primary Route 57:							
Control Section	P-57	0.0	11.0	11.0			32
Rumble Strip Section	P-57	34.4	47.4	13.0	Oct-96	Aug-97	40
Rumble Strip Section	P-57	47.4	58.4	11.0	Oct-96	Aug-97	32
Control Section	P-57	58.4	71.4	13.0			33
P-57 Control Section Total =				24.0			
P-57 Rumble Strip Section Total =				24.0			
P-57 Total Study Miles =				48.0			
Primary Route 60:							
Control Section	P-60	6.5	17.2	10.7			26
Rumble Strip Section	P-60	60.3	71.0	10.7	Oct-96	Aug-97	38
Control Section	P-60	71.0	76.8	5.8			37
Rumble Strip Section	P-60	81.2	87.0	5.8	Oct-96	Aug-97	45
P-60 Control Section Total =				16.5			
P-60 Rumble Strip Section Total =				16.5			
P-60 Total Study Miles =				33.0			
Non-Interstate Control Section Total =				**106.4**			
Non-Interstate Rumble Strip Totals =				**106.4**			
Non-Interstate Study Miles =				**212.8**			

TABLE A-3. GLOBAL STUDY SEGMENTS OFF-ROAD INTERSTATE CRASH SUMMARY

Segment Number	# of Crashes	Crash Rate	Severity Rate	# of Crashes	Crash Rate	Severity Rate	# of Crashes	Crash Rate	Severity Rate	# of Crashes	Crash Rate	Severity Rate	# of Crashes	Crash Rate	Severity Rate	# of Crashes	Crash Rate	Severity Rate
	Before			After			Percentage Reduction			Before			After			Percentage Reduction		
I90-1	17	0.255	0.720	16	0.223	0.557	5.9%	12.5%	22.6%	27	0.374	1.122	13	0.151	0.501	51.9%	59.6%	55.3%
I90-2	11	0.251	1.027	9	0.179	0.499	18.2%	28.7%	51.4%	32	0.436	1.323	25	0.302	0.906	21.9%	30.7%	31.5%
I90-3	35	0.295	0.954	24	0.174	0.486	31.4%	41.0%	49.1%	40	0.321	1.204	33	0.223	0.675	17.5%	30.5%	43.9%
I90-4	21	0.193	0.230	10	0.074	0.192	52.4%	61.7%	16.5%	13	0.257	1.088	15	0.283	0.678	-15.4%	-10.1%	37.7%
I90-5	6	0.161	0.348	6	0.155	0.440	0.0%	3.7%	-26.4%	7	0.145	0.476	9	0.129	0.345	-28.6%	11.0%	27.5%
I90-6	6	0.085	0.412	25	0.301	0.711	-316.7%	-254.1%	-72.6%	23	0.277	1.180	31	0.346	1.104	-34.8%	-24.9%	6.4%
I90-7	16	0.343	1.563	26	0.419	0.951	-62.5%	-22.2%	39.2%	25	0.434	1.633	25	0.382	1.358	0.0%	12.0%	16.8%
I90-8	26	0.228	0.640	33	0.244	0.741	-26.9%	-7.0%	-15.8%	5	0.096	0.212	6	0.096	0.304	-20.0%	0.0%	-43.4%
I90-9	11	0.182	0.546	12	0.206	0.670	-9.1%	-13.2%	-22.7%	9	0.165	0.476	14	0.246	1.319	-55.6%	-49.1%	-177.1%
I94-1	5	0.182	0.581	3	0.108	0.361	40.0%	40.7%	37.9%	6	0.209	1.182	4	0.153	0.382	33.3%	26.8%	67.7%
I94-2	2	0.117	0.527	2	0.112	0.224	0.0%	4.3%	57.5%	4	0.183	0.917	3	0.134	0.134	25.0%	26.8%	85.4%
I94-3	9	0.192	0.620	11	0.230	0.901	-22.2%	-19.8%	-45.3%	9	0.154	0.770	19	0.317	1.153	-111.1%	-105.8%	-49.7%
I94-4	17	0.233	1.070	20	0.280	0.574	-17.6%	-20.2%	46.4%	26	0.298	1.194	33	0.366	0.910	-26.9%	-22.8%	23.8%
I15-1	7	0.187	0.560	8	0.172	0.408	-14.3%	8.0%	27.1%	15	0.320	1.387	11	0.191	0.295	26.7%	40.3%	78.7%
I15-2	3	0.115	0.268	10	0.343	0.754	-233.3%	-198.3%	-181.3%	16	0.269	0.908	31	0.475	1.475	-93.8%	-76.6%	-62.4%
I15-3	10	0.286	1.175	2	0.049	0.148	80.0%	82.9%	87.4%	6	0.169	0.674	16	0.415	1.141	-166.7%	-145.6%	-69.3%
I15-4	17	0.239	0.898	17	0.213	0.452	0.0%	10.9%	49.7%	11	0.141	0.488	39	0.460	1.523	-254.5%	-226.2%	-212.1%
				Rumble Strip Segments									**Control Segments**					
Totals	**219**			**234**			**-6.8%**			**274**			**327**			**-19.3%**		
Averages*		**0.219**	**0.716**		**0.207**	**0.541**		**5.5%**	**24.4%**		**0.265**	**0.965**		**0.282**	**0.872**		**-6.4%**	**9.6%**

*Average crash and severity rates calculated by dividing total number of crashes by total vehicle miles.

TABLE A-4. GLOBAL STUDY SEGMENTS ROLLOVER INTERSTATE CRASH SUMMARY

Segment Number	# of Crashes	Crash Rate	Severity Rate	# of Crashes	Crash Rate	Severity Rate	# of Crashes	Crash Rate	Severity Rate	# of Crashes	Crash Rate	Severity Rate	# of Crashes	Crash Rate	Severity Rate	# of Crashes	Crash Rate	Severity Rate
	Before			After			Percentage Reduction			Before			After			Percentage Reduction		
I90-1	6	0.090	0.285	7	0.098	0.376	-16.7%	-8.3%	-30.0%	10	0.139	0.513	6	0.070	0.314	40.0%	49.6%	55.5%
I90-2	5	0.114	0.411	4	0.080	0.399	20.0%	30.1%	48.4%	10	0.136	0.464	8	0.097	0.362	20.0%	29.1%	38.3%
I90-3	9	0.076	0.447	9	0.065	0.210	0.0%	14.1%	0.7%	24	0.193	0.859	15	0.101	0.371	33.3%	43.9%	58.3%
I90-4	3	0.028	0.028	3	0.022	0.088	0.0%	19.8%	-87.1%	4	0.079	0.198	7	0.132	0.452	-75.0%	-66.8%	-42.9%
I90-5	2	0.054	0.241	4	0.104	0.249	-100.0%	-93.5%	-214.4%	3	0.062	0.145	4	0.057	0.115	-33.3%	7.6%	20.8%
I90-6	5	0.071	0.298	9	0.108	0.361	-80.0%	-52.8%	-39.5%	14	0.169	0.915	10	0.112	0.491	28.6%	33.9%	31.3%
I90-7	1	0.021	0.064	13	0.210	0.709	-1200.0%	-878.6%	-928.8%	14	0.243	0.938	17	0.259	1.129	-14.3%	-0.4%	-43.6%
I90-8	12	0.105	0.421	16	0.119	0.533	-33.3%	-12.7%	-101.8%	3	0.058	0.135	5	0.080	0.256	-66.7%	-38.8%	-30.9%
I90-9	3	0.050	0.116	5	0.086	0.361	-66.7%	-73.0%	-63.1%	5	0.092	0.366	12	0.211	1.214	-140.0%	-130.5%	-117.0%
I94-1	3	0.109	0.254	1	0.036	0.036	75.0%	75.2%	94.8%	4	0.139	1.113	3	0.115	0.344	25.0%	17.6%	74.6%
I94-2	1	0.059	0.059	0	0.000	0.000	100.0%	100.0%	100.0%	2	0.092	0.504	3	0.134	0.134	-50.0%	-45.7%	79.2%
I94-3	4	0.086	0.321	5	0.105	0.733	-25.0%	-22.5%	-51.4%	4	0.068	0.103	10	0.167	0.735	-150.0%	-143.9%	-225.2%
I94-4	9	0.123	0.658	5	0.070	0.182	44.4%	43.3%	69.1%	12	0.138	0.746	16	0.178	0.477	-41.7%	-37.1%	21.0%
I15-1	3	0.080	0.266	4	0.086	0.322	0.0%	19.4%	43.6%	8	0.171	0.896	7	0.121	0.226	25.0%	39.0%	76.0%
I15-2	1	0.038	0.038	7	0.240	0.754	-600.0%	-527.0%	-1004.6%	7	0.118	0.572	13	0.199	0.782	-71.4%	-56.3%	-42.3%
I15-3	1	0.029	0.086	1	0.025	0.074	0.0%	13.6%	56.8%	1	0.028	0.084	10	0.259	0.830	-900.0%	-823.1%	-423.1%
I15-4	8	0.112	0.547	5	0.063	0.138	25.0%	32.9%	74.4%	3	0.039	0.308	20	0.236	0.992	-566.7%	-512.9%	-431.9%
				Rumble Strip Segments									**Control Segments**					
Totals	**76**			**98**			**-28.9%**			**128**			**166**			**-29.7%**		
Averages*		**0.076**	**0.305**		**0.087**	**0.327**		**-12.4%**	**-8.8%**		**0.124**	**0.556**		**0.143**	**0.54**		**-14.8%**	**-6.0%**

* Average crash and severity rates calculated by dividing total crashes by total vehicle miles.

TABLE A-5. GLOBAL STUDY SEGMENTS OFF-ROAD PRIMARY CRASH SUMMARY

Segment Number	Before			After			Percentage Reduction			Before			After			Percentage Reduction		
	# of Crashes	Crash Rate	Severity Rate	# of Crashes	Crash Rate	Severity Rate	# of Crashes	Crash Rate	Severity Rate	# of Crashes	Crash Rate	Severity Rate	# of Crashes	Crash Rate	Severity Rate	# of Crashes	Crash Rate	Severity Rate
P1-1	0	0.000	0.000	1	0.129	1.029	-	-	-	3	0.066	0.264	4	0.072	0.108	-33.3%	-9.1%	59.1%
P1-2	0	0.000	0.000	0	0.000	0.000	-	-	-	2	0.117	0.117	2	0.112	0.503	0.0%	4.3%	-329.9%
P1-3	2	0.072	0.144	2	0.114	0.511	0.0%	-58.3%	-254.9%	5	0.304	1.095	4	0.245	0.675	20.0%	19.4%	38.4%
P1-4	2	0.209	1.150	4	0.436	1.635	-100.0%	-108.6%	-42.2%	4	0.377	0.377	3	0.290	0.676	25.0%	23.1%	-79.3%
P3-1	1	0.180	1.441	0	0.000	0.000	100.0%	100.0%	100.0%	1	0.217	1.732	0	0.000	0.000	100.0%	100.0%	100.0%
P20-1	5	0.199	0.637	1	0.034	0.034	80.0%	82.9%	94.6%	4	0.334	0.917	6	0.414	0.552	-50.0%	-24.0%	39.8%
P22-1	4	0.435	1.414	4	0.503	2.517	0.0%	-15.6%	-78.0%	2	0.503	1.510	2	0.558	1.117	0.0%	-10.9%	26.0%
P22-2	2	0.243	1.335	1	0.108	0.862	50.0%	55.6%	35.4%	3	0.962	4.490	3	0.908	3.026	0.0%	5.6%	32.6%
P24-1	1	0.144	0.432	3	0.315	1.051	-200.0%	-118.8%	-143.3%	3	0.432	1.727	3	0.315	0.526	0.0%	27.1%	69.5%
P49-1	7	0.669	1.242	3	0.225	0.375	57.1%	66.4%	69.8%	6	1.231	1.850	6	1.483	1.330	0.0%	-20.5%	28.1%
P57-1	1	0.046	0.046	2	0.081	0.364	-100.0%	-76.1%	-691.3%	7	0.302	1.509	10	0.350	1.190	-42.9%	-15.9%	21.1%
P57-2	3	0.113	0.529	2	0.068	0.068	33.3%	39.8%	87.1%	5	0.168	0.774	2	0.060	0.180	60.0%	64.3%	76.7%
P60-1	2	0.290	0.581	3	0.382	2.168	-50.0%	-31.7%	-273.1%	0	0.000	0.000	0	0.000	0.000	-	-	-
P60-2	3	0.140	0.465	2	0.084	0.462	33.3%	40.0%	0.6%	4	0.231	0.462	11	0.569	1.344	-175.0%	-146.3%	-190.9%
	Rumble Strip Segments									**Control Segments**								
Totals	**33**			**28**			**15.2%**			**49**			**56**			**-14.3%**		
***Averages**		**0.165**	**0.541**		**0.136**	**0.560**		**17.5%**	**-11.0%**		**0.240**	**0.809**		**0.240**	**0.621**		**0.0%**	**0.9%**

*Average crash and severity rates calculated by dividing total crashes by total vehicle miles.

TABLE A-6. GLOBAL STUDY SEGMENTS ROLLOVER PRIMARY CRASH SUMMARY

Segment Number	Before			After			Percentage Reduction			Before			After			Percentage Reduction		
	# of Crashes	Crash Rate	Severity Rate	# of Crashes	Crash Rate	Severity Rate	# of Crashes	Crash Rate	Severity Rate	# of Crashes	Crash Rate	Severity Rate	# of Crashes	Crash Rate	Severity Rate	# of Crashes	Crash Rate	Severity Rate
P1-1	0	0.000	0.000	1	0.129	1.029	-	-	-	0	0.000	0.000	0	0.000	0.000	-	-	-
P1-2	0	0.000	0.000	0	0.000	0.000	-	-	-	0	0.000	0.000	1	0.056	0.447	-	-	-
P1-3	0	0.000	0.000	1	0.057	0.170	-	-	-	2	0.122	0.365	1	0.061	0.491	50.0%	49.6%	66.4%
P1-4	2	0.209	1.150	4	0.436	1.635	-50.0%	-56.4%	-73.8%	0	0.000	0.000	0	0.000	0.000	-	-	-
P3-1	0	0.000	0.000	0	0.000	0.000	-	-	-	0	0.000	0.000	0	0.000	0.000	-	-	-
P20-1	1	0.040	0.119	0	0.000	0.000	0.0%	14.4%	14.4%	1	0.083	0.083	1	0.069	0.069	-	-	-
P22-1	1	0.109	0.326	1	0.126	1.007	0.0%	-15.7%	-15.7%	1	0.252	0.755	2	0.558	1.117	-100.0%	-121.8%	-158.8%
P22-2	0	0.000	0.000	0	0.000	0.000	-	-	-	2	0.641	5.131	0	0.000	0.000	100.0%	100.0%	100.0%
P24-1	0	0.000	0.000	1	0.105	0.841	-	-	-	1	0.144	0.144	0	0.000	0.000	100.0%	100.0%	100.0%
P49-1	5	0.478	0.860	1	0.075	0.075	80.0%	84.3%	93.5%	5	0.513	1.128	6	0.468	0.858	-20.0%	8.7%	23.9%
P57-1	0	0.000	0.000	0	0.000	0.000	-	-	-	1	0.043	0.345	3	0.105	0.490	-200.0%	-143.5%	-143.5%
P57-2	1	0.038	0.113	1	0.034	0.034	50.0%	54.8%	84.9%	4	0.135	0.673	1	0.030	0.090	66.7%	70.2%	-14.9%
P60-1	1	0.145	0.435	2	0.255	2.038	-100.0%	-75.5%	-455.8%	0	0.000	0.000	0	0.000	0.000	-	-	-
P60-2	1	0.047	0.372	2	0.084	0.462	-100.0%	-80.6%	-261.2%	3	0.173	0.289	4	0.207	0.775	-33.3%	-19.2%	-382.9%
	Rumble Strip Segments									**Control Segments**								
Totals	**12**			**14**			**-16.7%**			**20**			**19**			**5.0%**		
***Averages**		**0.060**	**0.200**		**0.068**	**0.346**		**-13.3%**	**-73.0%**		**0.098**	**0.348**		**0.081**	**0.308**		**17.3%**	**11.5%**

*Averages crash and severity rates claculated by dividing total crashes by total vehicle miles.

TABLE A-7. FOUR MILE STUDY SEGMENTS OFF-ROAD INTERSTATE CRASH SUMMARY

Segment Number	# of Crashes	Crash Rate	Severity Rate	# of Crashes	Crash Rate	Severity Rate	# of Crashes	Crash Rate	Severity Rate	# of Crashes	Crash Rate	Severity Rate	# of Crashes	Crash Rate	Severity Rate	# of Crashes	Crash Rate	Severity Rate
	Before			**After**			**Percentage Reduction**			**Before**			**After**			**Percentage Reduction**		
I15-1	4	0.454	0.454	2	0.183	0.183	50.0%	59.7%	59.7%	3	0.334	1.336	3	0.272	0.454	0.0%	18.6%	66.0%
I15-2	1	0.113	0.907	3	0.274	0.457	-200.0%	-142.5%	49.6%	3	0.334	1.336	2	0.181	0.181	33.3%	45.8%	86.5%
I15-3	1	0.113	0.907	1	0.091	0.274	0.0%	19.5%	69.8%	3	0.334	0.557	2	0.181	0.363	33.3%	45.8%	34.8%
I15-4	1	0.113	0.113	2	0.182	0.821	-100.0%	-61.1%	-626.5%	2	0.223	1.782	2	0.181	0.181	0.0%	18.8%	89.8%
I15-5	0	0.000	0.000	4	0.337	1.266	0.0%	0.0%	0.0%	6	0.432	2.590	5	0.338	1.421	16.7%	21.8%	45.1%
I15-6	2	0.157	0.314	6	0.431	0.863	-200.0%	-174.5%	-174.8%	10	0.221	0.553	24	0.479	1.418	-140.0%	-116.7%	-156.4%
I15-7	0	0.000	0.000	0	0.000	0.000	0.0%	0.0%	0.0%	1	0.086	0.689	12	0.947	2.446	-1100.0%	-1001.2%	-255.0%
I15-8	10	0.815	3.343	1	0.070	0.210	90.0%	91.4%	93.7%	1	0.090	0.090	3	0.250	0.998	-200.0%	-177.8%	-1008.9%
I15-9	6	0.322	1.019	5	0.213	0.298	16.7%	33.9%	70.8%	2	0.122	0.548	11	0.605	2.309	-450.0%	-395.9%	-321.4%
I15-10	4	0.262	1.181	4	0.267	0.869	0.0%	-1.9%	26.4%	3	0.158	0.263	11	0.560	1.577	-266.7%	-254.4%	-499.6%
I15-11	3	0.203	0.676	3	0.200	0.467	0.0%	1.5%	30.9%	5	0.219	0.700	13	0.568	2.009	-160.0%	-159.4%	-187.0%
I15-12	2	0.151	0.454	3	0.198	0.198	-50.0%	-31.1%	56.4%	3	0.269	1.077	1	0.083	0.083	66.7%	69.1%	92.3%
I90-1	11	0.423	1.115	11	0.387	0.527	0.0%	8.5%	52.7%	15	0.499	1.163	4	0.116	0.319	73.3%	76.8%	72.6%
I90-2	4	0.147	0.551	4	0.138	0.760	0.0%	6.1%	-37.9%	8	0.289	1.010	6	0.176	0.790	25.0%	39.1%	21.8%
I90-3	8	0.213	0.559	8	0.186	0.557	0.0%	12.7%	0.4%	28	0.410	1.230	22	0.286	0.936	21.4%	30.2%	23.9%
I90-4	8	0.246	0.738	7	0.188	0.431	12.5%	23.6%	41.6%	11	0.398	1.627	12	0.356	1.307	-9.1%	10.6%	19.7%
I90-5	3	0.093	0.748	8	0.216	0.648	-166.7%	-132.3%	13.4%	8	0.272	1.052	6	0.174	0.435	25.0%	36.0%	58.7%
I90-6	20	0.647	1.747	4	0.110	0.110	80.0%	83.0%	93.7%	14	0.479	1.780	9	0.268	0.774	35.7%	44.1%	56.5%
I90-7	6	0.207	0.275	3	0.083	0.278	50.0%	59.9%	-1.1%	6	0.221	0.700	4	0.119	0.119	33.3%	46.2%	83.0%
I90-8	8	0.276	0.276	2	0.055	0.110	75.0%	80.1%	60.1%	6	0.228	1.256	5	0.181	0.399	16.7%	20.6%	68.2%
I90-9	3	0.104	0.104	5	0.138	0.331	-66.7%	-32.7%	-218.3%	14	0.540	2.083	8	0.268	0.536	42.9%	50.4%	74.3%
I90-10	5	0.177	0.426	6	0.206	0.412	-20.0%	-16.4%	3.3%	7	0.214	0.704	8	0.167	0.438	-14.3%	22.0%	37.8%
I90-11	3	0.094	0.312	16	0.424	0.954	-433.3%	-351.1%	-205.8%	7	0.253	1.084	10	0.333	1.629	-42.9%	-31.6%	-50.3%
I90-12	3	0.094	0.593	8	0.212	0.583	-166.7%	-125.5%	1.7%	8	0.289	1.517	10	0.336	0.705	-25.0%	-16.3%	53.5%
I90-13	14	0.372	1.778	13	0.263	0.344	7.1%	29.3%	80.7%	8	0.318	1.233	15	0.531	2.338	-87.5%	-67.0%	-89.6%
I90-14	11	0.308	0.785	11	0.262	0.618	0.0%	14.9%	21.3%	0	0.000	0.000	0	0.000	0.000	0.0%	0.0%	0.0%
I90-15	9	0.252	0.701	11	0.260	1.065	-22.2%	-3.2%	-51.9%	2	0.096	0.192	4	0.160	0.521	-100.0%	-66.7%	-171.4%
I90-16	3	0.107	0.357	6	0.244	0.406	-100.0%	-128.0%	-13.7%	5	0.213	0.681	11	0.450	2.372	-120.0%	-111.3%	-248.3%
I90-17	4	0.147	0.550	4	0.142	0.710	0.0%	3.4%	-29.1%	3	0.128	0.298	3	0.123	0.695	0.0%	3.9%	-133.2%
I94-1	3	0.211	0.846	1	0.066	0.529	66.7%	68.7%	37.5%	5	0.348	1.808	1	0.076	0.076	80.0%	78.2%	95.8%
I94-2	2	0.150	0.300	2	0.159	0.159	0.0%	-6.0%	47.0%	1	0.070	0.556	3	0.229	0.688	-200.0%	-227.1%	-23.7%
I94-3	1	0.087	0.692	2	0.167	0.334	-100.0%	-92.0%	51.7%	3	0.206	1.307	2	0.134	0.134	33.3%	35.0%	89.7%
I94-4	0	0.000	0.000	3	0.258	1.033	0.0%	0.0%	0.0%	1	0.069	0.069	4	0.262	0.393	-300.0%	-279.7%	-469.6%
I94-5	2	0.177	0.975	3	0.258	0.430	-50.0%	-45.8%	55.9%	3	0.207	0.484	7	0.459	1.835	-133.3%	-121.7%	-279.1%
I94-6	3	0.266	0.443	1	0.086	0.688	66.7%	67.7%	-55.3%	3	0.201	0.201	4	0.253	1.265	-33.3%	-25.9%	-529.4%
I94-7	4	0.310	1.007	4	0.311	1.400	0.0%	-0.3%	-39.0%	2	0.138	0.758	4	0.295	1.108	-100.0%	-113.8%	-46.2%
I94-8	3	0.245	1.962	5	0.431	1.208	-66.7%	-75.9%	38.4%	7	0.499	1.996	4	0.279	0.698	42.9%	44.1%	65.0%
I94-9	4	0.327	1.226	2	0.173	0.173	50.0%	47.1%	85.9%	2	0.143	0.642	6	0.419	0.419	-200.0%	-193.0%	34.7%
I94-10	5	0.409	1.471	1	0.086	0.086	80.0%	79.0%	94.2%	3	0.214	0.855	2	0.140	0.140	33.3%	34.6%	83.6%
I94-11	1	0.090	0.090	5	0.446	0.803	-400.0%	-395.6%	-792.2%	3	0.212	0.847	9	0.614	1.977	-200.0%	-189.6%	-133.4%
I94-12	4	0.362	1.810	1	0.089	0.089	75.0%	75.4%	95.1%	4	0.285	1.282	6	0.405	1.486	-50.0%	-42.1%	-15.9%
I94-13	0	0.000	0.000	6	0.521	1.217	0.0%	0.0%	0.0%	7	0.521	1.861	6	0.426	0.923	14.3%	18.2%	50.4%
	Rumble Strip Segments									**Control Segments**								
Totals	**189**			**197**			**-4.2%**			**236**			**284**			**-20.3%**		
***Averages**		**0.227**	**0.748**		**0.211**	**0.531**		**7.0%**	**29.0%**		**0.272**	**1.004**		**0.294**	**0.932**		**-8.1%**	**7.2%**

*Average crash and severity rates claculated by dividing total crashes by total vehicle miles

TABLE A-8. FOUR MILE STUDY SEGMENTS ROLLOVER INTERSTATE CRASH SUMMARY

Segment Number	# of Crashes	Crash Rate	Severity Rate	# of Crashes	Crash Rate	Severity Rate	# of Crashes	Crash Rate	Severity Rate	# of Crashes	Crash Rate	Severity Rate	# of Crashes	Crash Rate	Severity Rate	# of Crashes	Crash Rate	Severity Rate
	Before			After			Percentage Reduction			Before			After			Percentage Reduction		
I15-1	2	0.227	0.227	1	0.091	0.091	50.0%	59.9%	59.9%	1	0.111	0.334	3	0.272	0.454	-200.0%	-145.0%	-35.9%
I15-2	1	0.113	0.907	1	0.091	0.274	0.0%	19.5%	69.8%	1	0.111	0.334	0	0.000	0.000	100.0%	100.0%	100.0%
I15-3	0	0.000	0.000	1	0.091	0.274	-	-	-	2	0.223	0.445	2	0.181	0.363	0.0%	18.8%	18.4%
I15-4	0	0.000	0.000	1	0.091	0.730	-	-	-	2	0.223	1.782	0	0.000	0.000	100.0%	100.0%	100.0%
I15-5	0	0.000	0.000	4	0.337	1.266	-	-	-	2	0.144	1.151	3	0.203	0.812	-50.0%	-41.0%	29.5%
I15-6	1	0.078	0.235	3	0.216	0.503	-200.0%	-176.9%	-114.0%	5	0.111	0.398	9	0.180	0.759	-80.0%	-62.2%	-90.7%
I15-7	0	0.000	0.000	0	0.000	0.000	-	-	-	0	0.000	0.000	8	0.631	1.815	-	-	-
I15-8	1	0.082	0.245	0	0.000	0.000	100.0%	100.0%	100.0%	0	0.000	0.000	1	0.083	0.665	-	-	-
I15-9	2	0.107	0.322	2	0.043	0.128	0.0%	59.8%	60.2%	1	0.061	0.487	4	0.220	1.210	-300.0%	-260.7%	-148.5%
I15-10	2	0.131	1.050	0	0.000	0.000	100.0%	100.0%	100.0%	0	0.000	0.000	4	0.204	0.763	-	-	-
I15-11	0	0.000	0.000	1	0.067	0.2000	-	-	-	1	0.044	0.350	9	0.393	1.660	-800.0%	-793.2%	-374.3%
I15-12	2	0.151	0.454	2	0.132	0.132	0.0%	12.6%	70.9%	0	0.000	0.000	1	0.083	0.083	-	-	-
I90-1	3	0.115	0.538	3	0.105	0.176	0.0%	8.7%	67.3%	5	0.166	0.698	2	0.058	0.261	60.0%	65.1%	62.6%
I90-2	2	0.073	0.147	3	0.104	0.657	-50.0%	-42.5%	-346.9%	3	0.108	0.252	3	0.088	0.498	0.0%	18.5%	-97.6%
I90-3	5	0.133	0.479	4	0.093	0.464	20.0%	30.1%	3.1%	9	0.132	0.381	6	0.078	0.338	33.3%	40.9%	11.3%
I90-4	3	0.092	0.369	2	0.054	0.296	33.3%	41.3%	19.8%	8	0.289	1.446	7	0.208	0.683	12.5%	28.0%	52.8%
I90-5	2	0.062	0.498	5	0.135	0.378	-150.0%	-117.7%	24.1%	5	0.170	0.713	3	0.087	0.348	40.0%	48.8%	51.2%
I90-6	3	0.097	0.550	1	0.027	0.027	66.7%	72.2%	95.1%	8	0.274	1.096	4	0.119	0.357	50.0%	56.6%	67.4%
I90-7	0	0.000	0.000	1	0.028	0.028	-	-	-	2	0.074	0.406	1	0.030	0.030	50.0%	59.5%	92.6%
I90-8	2	0.069	0.069	1	0.028	0.083	50.0%	59.4%	-20.3%	6	0.228	1.256	5	0.181	0.399	16.7%	20.6%	68.2%
I90-9	0	0.000	0.000	2	0.055	0.248	-	-	-	11	0.424	1.620	4	0.134	0.402	63.6%	68.4%	75.2%
I90-10	2	0.071	0.319	4	0.137	0.515	-100.0%	-93.0%	-61.4%	3	0.092	0.367	4	0.083	0.167	-33.3%	9.8%	54.5%
I90-11	3	0.094	0.312	5	0.133	0.318	-66.7%	-41.5%	-1.9%	5	0.181	1.012	5	0.166	1.164	0.0%	8.3%	-15.0%
I90-12	2	0.062	0.343	4	0.106	0.477	-100.0%	-71.0%	-39.1%	5	0.181	1.084	3	0.101	0.168	40.0%	44.2%	84.5%
I90-13	0	0.000	0.000	3	0.061	0.142	-	-	-	2	0.080	0.358	12	0.425	1.913	-500.0%	-431.3%	-434.4%
I90-14	6	0.168	0.533	5	0.119	0.428	16.7%	29.2%	19.7%	0	0.000	0.000	0	0.000	0.000	-	-	-
I90-15	3	0.084	0.336	8	0.189	0.828	-166.7%	-125.0%	-146.4%	1	0.048	0.144	3	0.120	0.401	-200.0%	-150.0%	-178.5%
I90-16	1	0.036	0.036	1	0.041	0.041	0.0%	-13.9%	-13.9%	3	0.128	0.596	9	0.368	2.126	-200.0%	-187.5%	-256.7%
I90-17	1	0.037	0.110	2	0.071	0.390	-100.0%	-91.9%	-254.5%	1	0.043	0.128	3	0.123	0.695	-200.0%	-186.0%	-443.0%
I94-1	1	0.070	0.211	0	0.000	0.000	100.0%	100.0%	100.0%	3	0.209	1.669	0	0.000	0.000	100.0%	100.0%	100.0%
I94-2	2	0.150	0.300	1	0.079	0.079	50.0%	47.3%	73.7%	1	0.070	0.556	3	0.229	0.688	-200.0%	-227.1%	-23.7%
I94-3	0	0.000	0.000	0	0.000	0.000	-	-	-	2	0.138	0.756	2	0.134	0.134	0.0%	2.9%	82.3%
I94-4	0	0.000	0.000	1	0.086	0.688	-	-	-	0	0.000	0.000	2	0.131	0.262	-	-	-
I94-5	2	0.177	0.975	1	0.086	0.258	50.0%	51.4%	73.5%	2	0.138	0.276	3	0.197	1.114	-50.0%	-42.8%	-303.6%
I94-6	1	0.089	0.089	1	0.086	0.688	0.0%	3.4%	-673.0%	2	0.134	0.134	2	0.126	0.696	0.0%	6.0%	-419.4%
I94-7	1	0.077	0.232	2	0.156	1.245	-100.0%	-102.6%	-436.6%	0	0.000	0.000	3	0.222	0.886	-	-	-
I94-8	1	0.082	0.654	2	0.173	0.345	-100.0%	-111.0%	47.2%	3	0.214	1.212	2	0.140	0.279	33.3%	34.6%	77.0%
I94-9	2	0.163	0.980	0	0.000	0.000	100.0%	100.0%	100.0%	0	0.000	0.000	2	0.140	0.140	-	-	-
I94-10	2	0.163	0.899	0	0.000	0.000	100.0%	100.0%	100.0%	1	0.071	0.570	0	0.000	0.000	100.0%	100.0%	100.0%
I94-11	1	0.090	0.090	2	0.178	0.535	-100.0%	-97.8%	-494.4%	1	0.071	0.071	5	0.341	1.091	-400.0%	-380.3%	-1436.6%
I94-12	3	0.271	1.719	0	0.000	0.000	100.0%	100.0%	100.0%	2	0.142	1.139	3	0.203	0.675	-50.0%	-43.0%	40.7%
I94-13	0	0.000	0.000	1	0.087	0.261	-	-	-	5	0.372	1.712	4	0.284	0.781	20.0%	23.7%	54.4%
	Rumble Strip Segments									**Control Segments**								
Totals	**65**			**81**			**-24.6%**			**114**			**149**			**-30.7%**		
***Averages**		**0.078**	**0.315**		**0.086**	**0.315**		**-10.3%**	**0.0%**		**0.132**	**0.603**		**0.154**	**0.587**		**-16.7%**	**2.7%**

*Average crash and severity rates calculated by dividing total crashes by total vehicle miles.

TABLE A-9. FOUR MILE STUDY SEGMENTS OFFROAD PRIMARY CRASH SUMMARY

Segment Number	# of Crashes	Crash Rate	Severity Rate	# of Crashes	Crash Rate	Severity Rate	# of Crashes	Crash Rate	Severity Rate	# of Crashes	Crash Rate	Severity Rate	# of Crashes	Crash Rate	Severity Rate	# of Crashes	Crash Rate	Severity Rate
	Before			After			Percentage Reduction			Before			After			Percentage Reduction		
P1-1	0	0.000	0.000	1	0.129	1.029	-	-	-	3	0.066	0.264	4	0.072	0.108	-33.3%	-9.2%	59.0%
P1-2	0	0.000	0.000	0	0.000	0.000	0.0%	0.0%	0.0%	2	0.185	0.185	2	0.179	0.807	0.0%	3.1%	-336.4%
P1-3	2	0.417	2.296	2	0.412	0.824	0.0%	1.3%	64.1%	3	0.515	0.515	1	0.186	0.186	66.7%	63.8%	63.8%
P1-4	0	0.000	0.000	2	0.449	2.467	-	-	-	1	0.209	0.209	2	0.425	1.274	-100.0%	-103.5%	-510.5%
P20-1	3	0.148	0.592	0	0.000	0.000	100.0%	100.0%	100.0%	3	0.544	1.813	0	0.000	0.000	100.0%	100.0%	-
P20-2	1	0.049	0.148	1	0.053	0.053	0.0%	-6.4%	64.5%	1	0.181	0.181	6	0.901	1.201	-500.0%	-396.6%	-562.2%
P22-1	1	0.237	1.893	1	0.274	0.821	0.0%	-15.7%	56.6%	2	1.079	3.238	0	0.000	0.000	100.0%	100.0%	100.0%
P22-2	3	0.710	1.183	3	0.821	4.654	0.0%	-15.7%	-293.4%	0	0.000	0.000	2	1.251	2.502	-	-	-
P22-3	2	0.374	2.055	1	0.166	1.330	50.0%	55.5%	35.3%	2	1.010	5.556	1	0.477	3.813	50.0%	52.8%	31.4%
P49-1	3	0.501	1.170	2	0.263	0.525	33.3%	47.6%	55.1%	5	0.849	1.529	6	0.795	2.518	-20.0%	6.4%	-64.7%
P57-1	1	0.122	0.976	1	0.110	0.110	0.0%	10.2%	88.8%	3	0.320	1.493	0	0.000	0.000	100.0%	100.0%	100.0%
P57-2	0	0.000	0.000	0	0.000	0.000	-	-	-	1	0.108	0.866	0	0.000	0.000	100.0%	100.0%	100.0%
P57-3	2	0.257	0.770	1	0.115	0.115	50.0%	55.4%	85.1%	1	0.112	0.112	2	0.202	0.607	-100.0%	-80.0%	-440.0%
P57-4	0	0.000	0.000	1	0.115	0.115	-	-	-	2	0.237	1.893	3	0.288	1.344	-50.0%	-21.7%	29.0%
P57-5	0	0.000	0.000	0	0.000	0.000	-	-	-	3	0.353	1.175	5	0.481	1.732	-66.7%	-36.5%	-47.4%
P60-1	2	0.777	1.553	1	0.341	2.726	50.0%	56.1%	-75.5%	0	0.000	0.000	0	0.000	0.000	-	-	-
P60-2	0	0.000	0.000	0	0.000	0.000	-	-	-	0	0.000	0.000	0	0.000	0.000	-	-	-
P60-3	2	0.135	0.607	2	0.122	0.670	0.0%	9.6%	-10.4%	4	0.376	0.753	6	0.502	1.003	-50.0%	-33.5%	-33.2%
	Rumble Strip Segments									Control Segments								
Totals	**22**			**19**			**13.6%**			**36**			**40**			**-11.1%**		
Averages*		**0.165**	**0.639**		**0.121**	**0.518**		**26.7%**	**18.9%**		**0.244**	**0.760**		**0.236**	**0.654**		**3.3%**	**13.9%**

*Average crash and severity rates calculated by dividing total crashes by total vehicles miles.

TABLE A-10. FOUR MILE STUDY SEGMENTS ROLLOVER PRIMARY CRASH SUMMARY

Segment Number	# of Crashes	Crash Rate	Severity Rate	# of Crashes	Crash Rate	Severity Rate	# of Crashes	Crash Rate	Severity Rate	# of Crashes	Crash Rate	Severity Rate	# of Crashes	Crash Rate	Severity Rate	# of Crashes	Crash Rate	Severity Rate
	Before			After			Percentage Reduction			Before			After			Percentage Reduction		
P1-1	0	0.000	0.000	1	0.129	1.029	-	-	-	0	0.000	0.000	0	0.000	0.000	-	-	-
P1-2	0	0.000	0.000	0	0.000	0.000	-	-	-	0	0.000	0.000	1	0.090	0.717	-	-	-
P1-3	2	0.417	2.296	1	0.206	0.618	50.0%	50.6%	73.1%	0	0.000	0.000	0	0.000	0.000	-	-	-
P1-4	0	0.000	0.000	2	0.449	2.467	-	-	-	0	0.000	0.000	0	0.000	0.000	-	-	-
P20-1	0	0.000	0.000	0	0.000	0.000	-	-	-	1	0.181	0.181	0	0.000	0.000	100.0%	100.0%	100.0%
P20-2	1	0.049	0.148	0	0.000	0.000	100.0%	100.0%	100.0%	0	0.000	0.000	1	0.150	0.150	-	-	-
P22-1	0	0.000	0.000	0	0.000	0.000	-	-	-	1	0.540	1.619	0	0.000	0.000	100.0%	100.0%	100.0%
P22-2	1	0.237	0.710	1	0.274	2.190	0.0%	-15.7%	-208.5%	0	0.000	0.000	2	1.251	2.502	-	-	-
P22-3	0	0.000	0.000	0	0.000	0.000	-	-	-	2	1.010	5.556	0	0.000	0.000	100.0%	100.0%	100.0%
P49-1	3	0.501	1.170	1	0.131	0.131	66.7%	73.8%	88.8%	4	0.679	2.378	6	0.795	2.518	-50.0%	-17.0%	-5.9%
P57-1	0	0.000	0.000	1	0.110	0.110	-	-	-	2	0.213	1.173	0	0.000	0.000	100.0%	100.0%	100.0%
P57-2	0	0.000	0.000	0	0.000	0.000	-	-	-	1	0.108	0.866	0	0.000	0.000	100.0%	100.0%	100.0%
P57-3	1	0.128	0.385	0	0.000	0.000	100.0%	100.0%	100.0%	1	0.112	0.112	1	0.101	0.303	0.0%	10.0%	-169.5%
P57-4	0	0.000	0.000	1	0.115	0.115	-	-	-	1	0.118	0.946	2	0.192	1.056	-100.0%	-62.3%	-11.6%
P57-5	0	0.000	0.000	0	0.000	0.000	-	-	-	0	0.000	0.000	1	0.096	0.289	-	-	-
P60-1	1	0.388	1.165	1	0.341	2.726	0.0%	12.2%	-134.0%	0	0.000	0.000	0	0.000	0.000	-	-	-
P60-2	0	0.000	0.000	0	0.000	0.000	-	-	-	0	0.000	0.000	0	0.000	0.000	-	-	-
P60-3	1	0.067	0.540	2	0.122	0.670	-100.0%	-80.6%	-24.1%	3	0.282	0.470	1	0.084	0.251	66.7%	70.4%	46.6%
	Rumble Strip Segments									Control Segments								
Totals	**10**			**11**			**-10.0%**			**16**			**15**			**6.3%**		
***Averages**		**0.062**	**0.240**		**0.074**	**0.350**		**-19.4%**	**-45.8%**		**0.109**	**0.421**		**0.088**	**0.306**		**19.3%**	**27.3%**

*Average crash and severity rates calculated by dividing total crashes by total vehicle miles.