Report No. UT- 05.12

EVALUATION OF FOUR RECENT TRAFFIC AND SAFETY INITIATIVES

Volume III: Centerline Rumble Strips on Rural, Two-Way, Undivided Highways

FINAL REPORT

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UDOT RESEARCH & DEVELOPMENT REPORT ABSTRACT

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16. Abstract

In the fall of 2003, the Utah Department of Transportation installed centerline rumble strips on various sections of highway US-6 between Spanish Fork, Utah and Soldier Summit, Utah as well as directly east of Wellington, Utah. Centerline rumble strips are a relatively new technique aimed at reducing the number of cross-over type accidents that occur on rural, undivided, two-way highways.

The combination of a literature review, a public opinion survey and a state of the practice survey has revealed favorable results towards centerline rumble strips. Positive findings include: (a) several reports stating a significant reduction in cross-over related accidents, injuries and fatalities, (b) high benefit to cost ratios, (c) versatile installation conditions, and (d) public approval and acceptance of centerline rumble strips.

However, centerline rumble strips are not flawless. Negative aspects include: (a) after installation data is inadequate for statistical comparison, (b) noise pollution, (c) various maintenance issues, (d) motorcyclist and bicyclist safety concerns, (e) emergency vehicle operation efficiency, and (f) potential risk of drivers correcting into the oncoming lane.

Published reports and the state of the practice survey provide evidence of the following. No geometric standards have been established for centerline rumble strips. Likewise, there are no standardized highway geometry dimensions when centerline rumble strips are considered. Similar to geometric considerations, highway operating factors have not been standardized. Correlations between the existing installation dimensions and their effectiveness to reduce crossover accidents, cost of installation, maintenance and other issues have not been made.

However, based on previously released reports, the statistical evidence of the public opinion survey, and the state of the practice survey data, it is recommended that the Utah department of Transportation should consider centerline rumble strips as a method of reducing cross-over related accidents on rural, two-way, undivided highways. There are many future research considerations that should be made concerning centerline rumble strips. Research may be conducted on accident reduction, rumble strip geometries, highway geometries, maintenance improvements, and noise reduction.

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1. INTRODUCTION

Cross-over and run-off-the-road crashes are a significant concern among traffic engineers in the United States and around the world. A cross-over crash occurs as a vehicle crosses over the centerline of a two-way highway resulting in a crash. A run-off-the-road crash occurs when a vehicle traverses the shoulder of a highway resulting in a crash. There are multiple potential causes of these types of crashes. The most common reasons include driver drowsiness, fatigue, and inattention. Consequently, each of these causes result from impaired visual capabilities of a driver.

Rumble strips are an increasingly common technology used to combat the effects of drowsiness, fatigue, and inattention. A rumble strip is a series of pavement indentations or protrusions located at a specific boundary of a road such as a highway shoulder or another lane of traffic. If a vehicle breaches this boundary, it will drive on to the rumble strips. As a vehicle drives on top of the rumble strips, the tires rise and fall as the pavement profile changes. The closely spaced intervals of the rumble strips and the oscillating motion of the tires create vibrations and sounds that a vehicle's occupants can sense. Hence, as the visual acuity of a driver decreases, rumble strips provide an alternative method informing a driver of his shift in position on a road.

Shoulder rumble strips (see Figure 1) have been installed on numerous highway shoulders throughout the United States. The purpose of shoulder rumble strips is to reduce run-off-the-road crashes. Shoulder rumble strips have been successful in significantly reducing the occurrence of run-off-the-road crashes. The success of shoulder rumble strips inspired the centerline rumble strip (CLRS) concept.

Figure 1: Shoulder Rumble Strips on Highway US-6
(Photo by Sam Richards 2004)

Centerline rumble strips are a relatively new application. As inferred by the name, centerline rumble strips are located along the centerline of an undivided, two-way highway (see Figure 2). The primary purpose of centerline rumble strips is to reduce and prevent crossover crashes that occur on undivided, two-way highways by providing an audible, vibratory warning to drivers. Reporting the advantages and disadvantages of centerline rumble strips and compiling a guidelines draft for the Utah Department of Transportation are the purpose of this report.

Figure 2: Centerline Rumble Strips on Highway US-6
(Photo by Sam Richards 2004)

1.1. Background

Highway US-6 is notorious for driver related injuries and fatalities. In response to the number of crossover type crashes occurring on Highway US-6, the Utah Department of Transportation has installed a total of 30 miles of centerline rumble strips thereon. Three installations are between Spanish Fork, Utah and Soldier Summit, Utah. There is one installation immediately east of Wellington, Utah (see Figure 3 and Table 1).

Figure 3: Approximate Locations of Centerline Rumble Strips on Highway US-6
(Map source: http://www.utah.com/maps/price/index.htm - arrows added)

Table 1: Route Post Boundaries of Centerline Rumble Strips on Highway US-6

	Route Post		
Location	East Boundary	West Boundary	Mileage
Between Spanish Fork	178	183	5
and Soldier Summit	189	197	8
	200	212	12
East of Wellington	249	255	5

Accompanying these installations, the Utah Department of Transportation requested an in depth analysis of centerline rumble strips. This report is to present the current status, advantages and disadvantages of centerline rumble strips and conclude with various research and usage recommendations.

1.2. Organization of the Report

Three techniques have been used to acquire data for this report. The report is organized such that the issues of centerline rumble strips are systematically addressed.

When supporting evidence from any of the data applies to a specific issue, that data is included in that section of the report. Chapter Two discusses the three data acquisition techniques. Chapter Three discusses the state of the practice of centerline rumble strip usage, mileage and geometries. After the state of the practice is established, Chapter Four presents the features and issues of centerline rumble strips. Finally, Chapter Five presents potential research and usage recommendations based on the issues discussed.

2. DATA COLLECTION AND ANALYSIS METHODS

Three methods for acquiring data were used in this report. The first method was the literature search. This provided a basis to establish the surveys which followed. Details about the each of the techniques are found in the following sections.

2.1. Literature Search

This portion of the study was started in May, 2004. The purpose of the literature search was to discover the benefits and issues that come with centerline rumble strips. Specific topics of research include safety improvements, cost of installation and maintenance, methods of research and operational improvements.

The majority of the literature was researched on the Internet. The remaining articles were hard copies or CD-ROM copies of the published documents.

In conjunction with the state of the practice survey, each of the state departments were invited to forward any published documents about centerline rumble strips that were in their possession.

2.2. Public Opinion Survey

The survey was prepared with the intention to discover if drivers of Utah's undivided highways were for or against future installations of centerline rumble strips. An anonymous survey was prepared. It was then cleared by the Institutional Review Board of Brigham Young University for research purposes. The survey consisted of 23 questions (see Appendix A). The list below outlines the distribution of question topics included in the survey:

- Four questions on driver demographics.
- Three questions on the effectiveness of centerline rumble strip road-signs.
- Seven questions on the drivers' behavioral reactions to centerline rumble strips.
- Two questions on lane visibility, demarcation or delineation.
- Three questions on available reaction times of centerline rumble strips.
- Two questions on vehicle control.
- One question on collision reduction.

- One question on future installation of centerline rumble strips.

In early July, 2004, several gas stations located in the cities of Spanish Fork, Price and Helper, Utah were identified. Management/owners were consulted to seek approval to conduct the survey on their property and to their customers. The discussion included a station where we could operate the survey and display a poster. From the station, surveys could be collected and incentives distributed. It was explained to the owners or managers that participants in the survey would receive a coupon redeemable in the store. The store clerks would collect the coupons. At the end of the day, the store would be reimbursed according the value of the number of coupons collected throughout the day. Most of the establishments readily accepted our proposal.

There were some concerns raised by management. One of the concerns raised by management at this time was that customers may become disgruntled with those conducting the survey. It was agreed that customers would be asked once and only once to take the survey. If they declined, the survey conductors would respect the customer's choice. Another concern was that the survey could be too personal. At that time, we presented a copy of the survey for them to review. They were contacted at a later date to see if the subject matter of the survey was acceptable.

2.2.1. Conducting the Public Opinion Survey

During the latter two weeks of July, appointments were made with these same gas stations. These appointments were arranged so that management knew when the surveys would be conducted. The surveys were conducted at five locations (see Table 2).

Table 2: Public Opinion Survey Location Information

Location	**Address**	**City**	**Owner/ Manager**
Market Express	121 North Carbonville Road	Price	Paula
Extra Mart	1085 North Chappellor Road	Spanish Fork	Laura
Tucker Turnout	RP 203 (approx.)	US-6	UDOT
Swift Stop'n'Shop	156 North Main	Helper	Chriss
Jackrabbit	3601 Powerhouse Road	Spanish Fork	Robert/Sheree

Upon arrival, the store managers were shown the coupons that would be distributed that day. They were instructed that the coupons were good for that day only. The coupons also required a signature from one of the survey conductors. If the coupon did not meet the criteria, the coupon was to be rejected (see Figure 4).

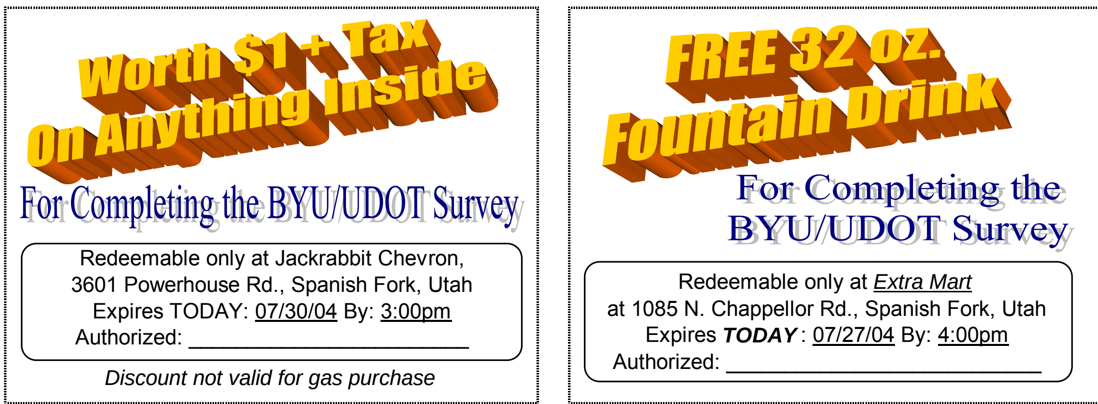

Figure 4: Public Opinion Survey Coupons

The Tucker Turnout is a rest stop located off the side of Highway US-6 near route post 203. At this location, monitoring the distribution of coupons was not reasonable. Therefore, candy bars, cookies and crackers were distributed to survey participants as a reimbursement for their time.

2.2.2. Analysis Procedure of the Public Opinion Survey

A total of 533 surveys were collected. Surveys were tallied in a customized Microsoft Excel file. A Visual Basic user-form was programmed to automatically tabulate the answers of each survey and record the number of surveys completed. Surveys were also numbered. This way, accuracy of the spreadsheet could be checked.

After the survey data had been recorded, an appointment was made with Dr. Dennis Eggett at the Center for Statistical Consultation and Collaboration Research of Brigham Young University. The Excel spreadsheet file was reconfigured by Dr. Eggett for the SAS statistical analysis computer program (SAS version 9.1.3 2003) used by the Center for Statistical Consultation and Collaboration Research. The SAS program performs statistical operations to a given data set. It was through the use of this program that the frequency and Chi-square test results of this report were obtained (see Appendix B).

There were two main objectives to the analysis of the survey. The first objective was to analyze the survey using the entire sample. Analysis of the entire sample was completed to see if there is a general consensus among drivers concerning centerline rumble strips. The second objective was based upon the demographic responses of the survey participants. The reason this type of analysis was performed is to determine if there is a specific group of people that are directly affected by the use of centerline rumble strips that might be overshadowed by the results of the entire survey. There may be certain aspects of centerline rumble strips that have a greater impact on a particular group than on the sample population.

2.3. State of the Practice Survey

At the time of this report, centerline rumble strips had not been standardized by any government authority. The state of the practice survey was designed to compile the various technical elements of centerline rumble strips. The survey was subdivided into seven categories (see Appendix C).

- Information of the responding agency
- Status
- Types and dimensions
- Highway geometry and operations
- Costs
- Noise generation and control
- Crash reduction and safety

The information of the responding agency section provided identification of which states had responded to the survey, the contact information of the engineer responsible for completing the survey and the date the survey was completed. The remainder of the survey addressed specifics related to centerline rumble strips. If a state indicated that it is not using centerline rumble strips, it could stop the survey at that point. States that have centerline rumble strips completed the remainder of the survey.

2.3.1. Conducting the State of the Practice Survey

The survey was prepared in two ways. There was an electronic copy prepared as well as paper copy. The electronic copy was created in Microsoft Excel. Option buttons and scroll boxes provided multiple choice type responses to many of the questions. Textboxes were provided where a short answer type response was required. The paper version was formatted similarly to the electronic version. Since scroll boxes are not available in the paper version, lists containing the same answers were included below the question.

In early November 2004, the state of the practice survey was mailed to all 50 state departments of transportation, as well as the District of Columbia Department of Transportation and Puerto Rico Department of Transportation. Each survey was individually addressed to a specific engineer at the state department of transportation. A cover letter explaining the reason for the survey and a request to participate was included with the hard copy. The engineers that received the survey were found on an AASHTO roster at the following website: http://transportation1.org/scote/doc/Roster.pdf.

Approximately one week after the paper copy of the survey was mailed; an electronic copy of the survey was e-mailed to the same engineers. Therefore, each department of transportation received two copies of the survey. Both copies of the survey invited the engineers to forward the survey to other branches of the department to obtain survey data if necessary.

The departments were encouraged to complete the survey by December 31, 2004. Completed surveys were returned by e-mail or mail to addresses that were included in the survey.

By January 1, 2005, only 17 surveys had been completed and returned. The deadline for the survey was extended to February 1, 2005. During the month of January, states that had not previously responded to the survey were contacted. Contact efforts were made by telephone. If a survey was misplaced, another copy of the survey was e-mailed to a given address.

2.3.2. Analysis Procedure of the State of the Practice Survey

A total of 41 state of the practice surveys were returned in either electronic and paper form. Each survey was recorded in a Microsoft Excel spreadsheet. Initially, all the survey results were recorded onto a single spreadsheet. A second spreadsheet was created where some adjustments to the information could be made. First, only the information gathered from the states that use centerline rumble strips was included. Second, units of measurement were adjusted for consistency. This allowed the totals, averages, maximums and minimum values for the various elements of the survey to be calculated. In order for the units to be consistent, some responses had to be recalculated.

The sample size of the survey is not large enough to obtain reliable Chi-square analysis results. Therefore, unlike the public opinion survey, conclusions based on the state of the practice survey results are from descriptive statistics only.

3. CENTERLINE RUMBLE STRIP USAGE AND GEOMETRIES

As previously mentioned, centerline rumble strips are a relatively new approach to reducing crossover type crashes. This is the primary reason for installing centerline rumble strips. This section of the report discusses the level of usage, mileage, or application of centerline rumble strips, the geometric dimensions of the rumble strips, influencing highway geometry, and operations effecting their installation.

3.1. Usage

Prior to this report, the latest information on the status of centerline rumble strips was obtainable from a report by the Massachusetts Highway Department. This report identified twenty states and one Canadian province using centerline rumble strips (Noyce and Elango 2004). The recently published NCHRP synthesis 339: Centerline Rumble Strips reported twenty-two states and two Canadian provinces that use centerline rumble strips (Russell and Rys 2005). These numbers resulted from a 90 percent response rate survey. There is a slight increase in a two year period between the releasing of these reports. The Utah Department of Transportation and Brigham Young University (UDOT/BYU) conducted a state of the practice survey in late 2004 and early 2005. The survey had a 79 percent response rate. In this survey, 18 states reported the use of centerline rumble strips at various levels.

The NCHRP study reported 21 states using CLRS; the BYU survey received responses from 17 states using CLRS. There are four more states that use CLRS but did not respond to the BYU survey. Hence, the number of states using CLRS did not change between the two surveys. Also, there is one state that has some small installations of centerline rumble strips that have been installed at the request of the public. This state responded as not using centerline rumble strips on the survey.

Centerline rumble strip technology is expanding out of North America. A report released at The Applications of Advanced Technologies in Transportation Engineering International Conference stated research on centerline rumble strips in Japan (Hirasawa, Asano, and Saito 2004).

3.2. Centerline Rumble Strip Mileage in the United States

The mileage of centerline rumble strips installed in the United States according to UDOT/BYU state of the practice survey totaled 2403.7 miles as of February 1, 2005. The total number of miles on rural, two-way, two-lane, undivided highways is 2194.7 miles. There are 209 miles of centerline rumble strips on multilane highways. This assumes that a multilane highway has at least four total lanes. By observation, the main application of centerline rumble strips is on rural, two-way, two-lane undivided highways.

One state installed centerline rumble strips on double yellow curved sections only. Many of the states commented that the installations were still experimental.

3.3. Centerline Rumble Strip Type and Geometry

The dimensions of centerline rumble strips have not been standardized. Thus, there is a variety of dimensions used among the state departments. The dimensions considered in the state of the practice survey include:

- Shape
- Length
- Width
- Depth
- Spacing

The state of the practice survey compiled data of the measurable dimensions such as the length, width, and depth of centerline rumble strips vary among departments. Table 3 shows the statistics of the reported dimensions received in the survey. A schematic diagram of these dimensions is available in Appendix C: Figure 1 (see Appendix D for complete centerline rumble strip dimension data).

Table 3: UDOT/BYU State of the Practice Survey CLRS Dimensions

Dimension	Maximum	Minimum	Mode	Average
Length (in)	8	5	7	6.900
Width (in)	24	6	16	14.421
Depth (in)	0.6125	0.315	0.5	0.478
Spacing (in)	24	12	12	15.294

The results of the state of the practice survey show that most centerline rumble strips are milled installations. A variety of potential milled rumble strip shapes were provided in the survey. All of the milled rumble strips have a plan view rectangular shape. The profile shape of the milled rumble strip is concave. Alternatively, a few states use a raised profile rumble strips. These are circular or rectangular in shape depending on the manufacturer and have a convex shape against the pavement profile. Currently, the shape of the rumble strip is determined by the type of installation process.

"There are three different types of rumble strips that have previously been or are currently being used: milled, rolled, and formed" (Perrilo 1998). However, rolled and formed rumble strips have no record of use as centerline rumble strips.

In an effort to understand the effects of centerline rumble strips on vehicles and drivers, departments have conducted field tests that compare various dimensions. There are multiple dimensional combinations that may be tested that could enhance the effectiveness of centerline rumble strips.

3.4. Highway Geometry

Rumble strip geometry is affected by the accompanying highway geometry. Consequently, the pattern chosen by a transportation agency is typically governed by the existing dimensions of the highway. These dimensions include but are not limited to the lane width, cross sectional width, and shoulder width. Other considerations are the presence and location of shoulder rumble strips and available paved median space.

Pennsylvania is an example of how highway dimensions affect the layout of centerline rumble strips on a highway. The criteria for centerline rumble strip installation revolves around 11 foot lane widths and three foot shoulders. If the highway geometry is greater than these values, then Detail #1 pattern is used (see Figure 5). Otherwise, Detail #2 is used.

Roadway Description	Typical Drawing Detail
* Roadway with 12 feet or greater lane width and minimum of 3 feet of paved shoulder	Detail #1
* Roadway with 11 feet lane width and a minimum of 3 feet of paved shoulder	Detail #1 or Detail #2
* Roadway with 11 feet lane width and less than 3 feet of shoulder or no shoulder	Detail #2
* Roadway with 10 feet lane width with or without	Detail #2
* Roadway with less than 10 feet lane width	Consult Bureau of Highway and Traffic Safety Engineering

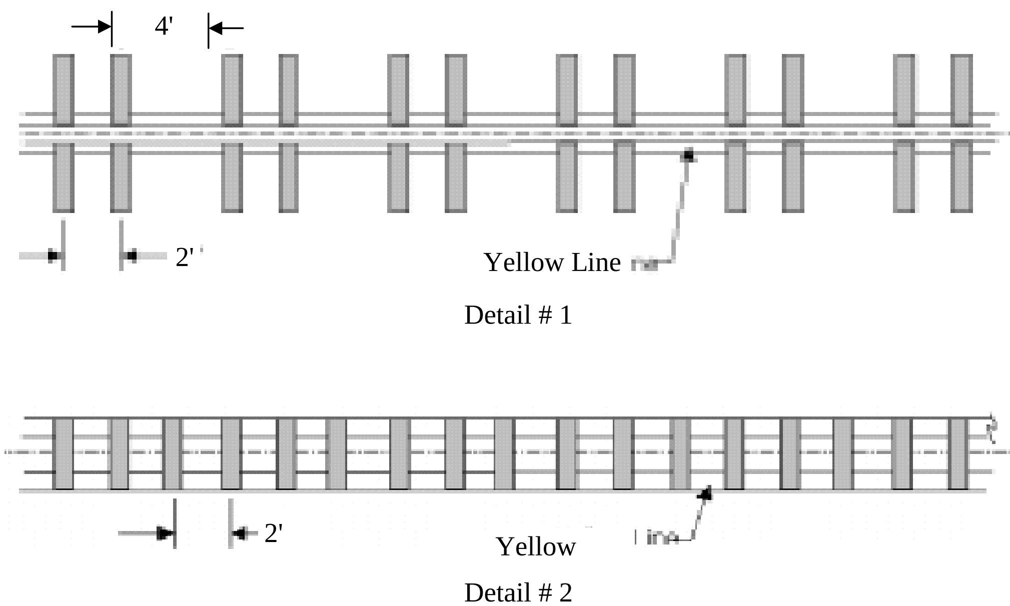

Figure 5: Pennsylvania Patterns for Centerline Rumble Strips
(Source: Russell and Rys 2005)

The state of Minnesota has drafted similar guidelines regarding the installation of centerline rumble strips regarding lane width compared to Pennsylvania. Both states have a minimum 10 foot lane width requirement. Centerline rumble strips are recommended on 11 foot and 12 foot lanes (see Table 4). If the lanes are 10 feet wide, centerline rumble strips are recommended if lane width can be borrowed from the shoulder. Centerline rumble strip installation on any lane smaller than 10 feet wide is not recommended.

Another consideration mentioned by the Minnesota draft is the number of lanes. Each potential case for centerline rumble strips is based on two-lane and four-lane highways.

Table 4: Minnesota Highway Geometric Considerations for CLRS

Roadway Description		CLRS Installation Recommended?
2-lane or 4-lane undivided with 12' or 11' lanes, with or without paved shoulders	-	YES
2-lane or 4-lane undivided with 10' or less lanes, with or without paved shoulders	-	YES - if min. 10' driving lane can be maintained by "borrowing" width from the shoulder, otherwise NO
2-lane or 4-lane undivided with 10' or less lanes, without paved shoulders	-	NO

(Source: Russell and Rys 2005)

Missouri recommends centerline rumble strips based on the roadway cross section. Centerline rumble strips are recommended on widths greater than 24 feet. Design exceptions are made for roadway widths between 20 feet and 24 feet (Russell and Rys 2005). The lone installation in Delaware is composed of 12 foot lanes with 10 foot shoulders (Delaware 2002). The states of California and Oregon make no recommendations based on the lane width, cross section width or shoulder sizes (Russell and Rys 2005). One approach that Oregon does consider is based upon the available paved median. If a paved median greater than four feet is available, two rows of rumble strips are installed. Likewise, if less than four feet is available, one row is installed. If there is no paved median or only a centerline, another layout is used (Russell and Rys 2005).

The state of the practice survey compiled the following data (see Table 5). Appendix D provides a complete summary of the UDOT/BYU state of the practice survey results on highway geometry. The table may appear to be misleading because four of the six highway dimensions mention minimum dimensions (the last four rows of the table) while the second column is a maximum statistic. The entries show the maximum values for the minimum dimension requirements.

Table 5: UDOT/BYU State of the Practice Survey Highway Geometry Statistics

Highway Dimension	Maximum	Minimum	Mode	Average
Flush Median Width (in)	72	8	48	37.6
Number of Rows of CLRS	2	1	1	1.158
Minimum Lane width (ft)	12	10	12	11.163
Minimum Cross Section Width (ft)	30	20	N/A	24.6
Minimum Shoulder Width (ft)	6	0	3	3.14
Minimum Shoulder Rumble Strip Offset (in)	12	0	N/A	4.6

Not mentioned in the state of the practice survey is a minimum pavement thickness. Pennsylvania and Minnesota use a minimum layer thickness of 2.5 inches. Missouri recommends a 3.75 inch minimum layer thickness (Russell and Rys 2005).

3.5. Highway Operations

Various operational requirements have been set among the states. Design considerations when installing the centerline rumble strips include minimum speed, highway volume, passing zones, and signs.

3.5.1. Speed Requirements

Some departments have established minimum design speeds to permit centerline rumble strips. According to the state of the practice survey and the NCHRP Synthesis 339, the minimum speed limits for centerline rumble strip installations range from 50 mph to 55 mph (Russell and Rys 2005). Evidence supporting these minimum speed limit decisions was not found in the literature.

One report tested vehicle mean speeds when centerline rumble strips were and were not present. It stated that the centerline rumble strip effects “on mean speed and on speed variance were mixed and made it difficult to draw meaningful and accurate conclusions” (Donnell, Mahoney and Porter 2003). Another report stated, “The average speeds on the section with the rumble strips are almost equal on the section without rumble strips”

(Hirasawa, Asano, and Saito 2004). This report analyzed multiple speeds and multiple rumble strip depths but did not recommend a minimum speed limit.

3.5.2. Lane Width Requirements

Lane width requirements may be specified in the guidelines of a state concerning centerline rumble strip installations. Reasoning behind minimum lane width requirements were not directly supported by any literature. Some considerations for minimum lane widths may include vehicle tracking on corners, vehicle widths, shoulder width and right-of-way acquisition.

A report on lateral vehicle displacement measured the effect of centerline rumble strips in combination with lane widths. Centerline rumble strips causes vehicles to laterally displace towards the shoulder. The research recorded significant lateral displacements of vehicles between similar road sections where centerline rumble strips were present and where they were not present. In a study using two lane widths, the wider lane (12 ft.) had an average displacement of .46 feet farther from the centerline with centerline rumble strips than without. On the narrower lane (11 ft.) the displacement was 0.25 feet farther from the centerline with centerline rumble strips than without (Donnell, Mahoney and Porter 2003). The trend in the lateral vehicle placement when centerline rumble strips are present may imply that at a given lane width, vehicles will displace towards the centerline due to a lack of shoulder space. This may have an effect on specifying a minimum lane width.

Closely related to a minimum lane width is a minimum cross-section width. This considers the presence of shoulders and multiple lanes. Once again, there are some states that have specified minimum cross-sectional widths for centerline rumble strip installations. No evidence of minimum cross-section width and centerline rumble strip correlations was discovered in the literature.

3.5.3. Centerline Rumble Strip Road Signs

Three questions of the public opinion survey specifically addressed the effects of centerline rumble strip road signs. These road signs are located where the centerline rumble strip installation begins. Accompanying the yellow diamond warning sign is a rectangular sign indicating the mileage of the installation (see Figure 6).

Figure 6: Centerline Rumble Strip Sign
(Photo by Sam Richards 2004)

Question 5 in the public opinion survey asked drivers if they have seen the centerline rumble strip road sign. The public opinion survey revealed that approximately two-thirds of the drivers surveyed had seen the centerline rumble strip road sign (see Table 6).

Table 6: Frequency Results of Question 5 of the Public Opinion Survey

Driver Saw the Sign	Survey Response	Percent Response	Cumulative Percent
Yes	346	68%	68%
No	165	32%	100%
Missing	22		

Providing a cross-examination of the survey results, Chi-square analysis of whether the road sign had been seen had statistically significant results when compared with other questions in the survey. Some inferences that were significant at a 95 percent confidence ($p \leq 0.05$) include that younger drivers are less likely to notice the road signs, and drivers of compact cars had greater difficulty seeing the signs while heavy truck drivers found the signs highly visible.

Question 5 had a clause in it that prompted the survey participants skip or answer question 5.1. Drivers that had not seen the road-sign were prompted to skip this question. Therefore, this question was addressed specifically to those who have seen the signs. Based on the frequency results of this question, the drivers that saw the signs had an increased awareness of the presence of centerline rumble strips (see Table 7). If such is the case, the signs are beneficial in reducing potential adverse effects caused by confusing centerline rumble strips and shoulder rumble strips.

Table 7: Frequency Results of Question 5.1 of the Public Opinion Survey

CLRS Signs are Effective	Survey Response	Percent Response	Cumulative Percent
Strongly Agree	40	15%	15%
Agree	140	53%	68%
No Opinion	49	19%	87%
Disagree	31	12%	98%
Strongly Disagree	4	2%	100%
Missing	82		

Two Chi-square tables analyzing demographic differences showed significant probabilities. It appears that female drivers feel that the road signs are less effective than male drivers. Some of the high contribution cells in the cell Chi-square show that fewer young drivers than expected responded after seeing the signs to look for the centerline rumble strips. The middle two groups are neutral in their opinions of the signs. The “Over 50” group, which appeared to be the most attentive to the signs, felt the strongest about the ineffectiveness of the signs.

Question 5.2 is a continuation of the previous two questions. There are two paths to gain awareness of centerline rumble strips on a highway. First, a driver sees the road sign, the sign effectively warns the driver of the centerline rumble strips and the driver looks for the centerline rumble strips. Second, a driver does not see the sign but recognizes and observes the presence of centerline rumble strips. Most of the drivers believe that centerline rumble strips are easily visible (see Table 8).

Table 8: Frequency Results of Question 5.2 of the Public Opinion Survey

CLRS are Visible	Survey Response	Percent Response	Cumulative Percent
Yes	360	82.4%	82.4%
No	77	17.6%	100.0%
Missing	96		

The positive response to this question could mean two things. First, road signs increase the awareness of drivers toward centerline rumble strips or, second, centerline rumble strips are visible enough by themselves that signs are not necessary. These two conclusions are counteractive. In consideration of this possibility, the safer choice is to install centerline rumble strip road-signs. However, other considerations could be included to determine the necessity of the signs.

4. ASPECTS AND ISSUES OF CENTERLINE RUMBLE STRIPS

Centerline rumble strips are a relatively new technology. Associated with a new technology are various benefits and concerns. The major advantages of centerline rumble strips include improving highway safety by reducing cross over crashes, low installation costs with high cost effectiveness, versatile installation conditions, public approval or acceptance of the technology, a positive reaction to centerline rumble strip contact while driving and improved driving confidence. The disadvantages are noise, premature pavement deterioration, lack of statistical evidence and vehicle operation concerns.

4.1. Improved Highway Safety

If centerline rumble strips improve highway safety, then the technology becomes advantageous to the traffic engineer. Major causes of crossover crashes are fatigue, drowsiness and inattention. These causes limit the visual accuracy of a driver. Centerline rumble strip technology is designed to appeal to alternative senses of the driver when sight is impaired. When a driver realizes that his vehicle is veering out of its lane, the driver can react and correct the vehicle. This is the process of how centerline rumble strips may reduce crossover crashes.

4.1.1. Reduction in Cross-Over Crashes

The existing literature on centerline rumble strips shows an encouraging yet unproven highway safety technology. State departments across the country are excited about the potential of centerline rumble strips to reduce crossover crashes. For example, the state of Idaho conducted a three year study from 1997 through 1999. They observed 213 vehicle crashes on a given segment of highway. Mark Strait, of Idaho's Office of Highway Safety said, "Centerline rumble strips might have prevented 14 percent of the 213 crashes had they been in place." The study also showed that 21 percent of the 62 multiple-vehicle crashes were "sideswipes" involving vehicles traveling in the opposite directions; contact usually resulted when one of the vehicles crossed the centerline (Idaho Transporter 2004).

There have been a few states that have used centerline rumble strips long enough that before and after studies have been conducted. Of the literature that has been researched, all the reports have shared positive information on the success of centerline rumble strips to reduce cross-over crashes. By success, it means a reduction in sideswipe collisions and head-on collisions when compared to the trends and patterns of the before portion of the study.

The state of Colorado had reported data of before centerline rumble strip and after centerline rumble strip periods of 44 months each on a certain stretch of State Highway 119 (see Table 9).

Table 9: Colorado Crash Data

	7/1/92 - 3/1/96 (44 months) Before Construction	7/1/96 - 3/1/2000 (44 months) After Construction	Percent Change
Head-on crashes	18	14	
Head-on crashes per million vehicles	2.91	1.92	-34.1%
Sideswipe opposite direction	24	18	
sideswipe crashes per million vehicles	3.88	2.46	-36.5%
Average ADT	4628	5463	18.0%

(Source: Outcalt 2001)

From the Colorado report, centerline rumble strips have reduced head-on crashes by 34.1 percent and sideswipe crashes by 36.5 percent while AADT increased by 18 percent by the year 2000 (Outcalt 2001).

Delaware was recognized for a before and after study about the installation of centerline rumble strips on a particularly busy undivided highway. The periods of study were longer and even more impressive results were obtained (see Table 10).

Table 10: DelDOT Before - After Crash Summary Data

	Average number of Accidents per Year		
Crash Type	Before Period 8/91 - 7/94 (3 years)	After Period 12/94 - 11/02 (8 years)	Percent Change
Head-on	2/year	0.1/year	-95%
Drove Left of Center	2/year	0.8/year	-60%
Property Damage	6.3/year	7.1/year	13%
Injury	4.7/year	4.9/year	4%
Fatal	2/year	0/year	N/A
Total	13/year	12/year	-8%
Average Daily Traffic	16500 (1994)	22472 (2002)	+4% yearly

(Source: Delaware, 2002)

It is not a surprise that the Delaware Department of Transportation was recognized for the success of centerline rumble strips when the number of reported head-on collisions dropped by 95 percent, drove-left-of-centerline crashes dropped by 60 percent, and there were zero fatalities in the eight years since centerline rumble strips were in stalled in 1994. There is an interesting observation in that property damage crashes and injury crashes increased over the same period.

Pennsylvania had similar results to Delaware in terms of fatality reduction. After installing centerline rumble strips on U.S. highway 322 in 1993, there were no fatalities for the following six years. There were other operational improvements included in the upgrade that effected safety (NCHRP Objective 18).

The United States is not the only place to have success with centerline rumble strips. In a recently released report from a Japanese study (Hirasawa, Asano, and Saito 2004), it was noted that, “since installation, 16 months have elapsed, during which time no head-on collisions have occurred.”

Supporting the statistical observations, the public opinion survey inquired to know if the public believes that centerline rumble strips improve highway safety. Question 9 asks if centerline rumble strips significantly reduce head-on collisions. The results show that drivers generally believe that centerline rumble strips do reduce head-on collisions (see Table 11).

Table 11: Frequency Results of Question 9 of the Public Opinion Survey

CLRS Reduce Collisions	Survey Response	Percent Response	Cumulative Percent
Yes	93	17%	17%
Probably So	224	42%	60%
No Opinion	171	32%	92%
Probably Not	28	5%	97%
No	16	3%	100%
Missing	1		

4.1.2. Statistically Inadequate After Data

In spite of the promotional reports in favor of centerline rumble strips, one report suggests that the statistical analysis employed by these state departments is not accurate. The AASHTO/NCHRP Strategic Highway Safety Plan website (NCHRP Objective 18) quotes the Persaud, Retting, and Lyon report stating, "Due to the "regression to the mean" bias, the estimates of effectiveness are probably inflated to some degree. Thus, there remains a need for well-designed before/after studies that can produce more accurate results of effectiveness."

To correct the inflated results, Persaud, Retting, and Lyon conducted an empirical Bayes theorem analysis to the results obtained by seven departments that had conducted simple before and after studies of centerline rumble strips. The results of this analysis can be found in Table 12 and Table 13.

Table 12: Summary of Treatment Site Data Used in the Analysis

			Before Period				After Period			
			Mile	Average	Crash Count		Mile	Average	Crash Count	
State	Miles	Sites	Years	AADT	Total	Injury	Years	AADT	Total	Injury
California	47.8	29	206.5	9235	679	257	112.5	10430	351	144
Colorado	16.9	10	118.4	5000	551	262	84.6	6154	415	187
Delaware	2.9	1	8.4	16500	34	16	21.3	21685	82	38
Maryland	30.4	11	91.4	11680	156	55	42.5	12991	55	14
Minnesota	66.2	24	508.6	9305	751	156	158.6	10315	275	41
Oregon	3.1	2	22.8	11400	31	20	4.6	11150	6	3
Washington	43.5	21	166.5	7290	308	116	173.3	7963	297	109
Total	210.8	98.0	1122.6	8829	2510.0	882	597.3	9668	1481	536

(Source: Persaud, Retting, and Lyon 2003)

Table 13: Composite Results

			Crashes Recorded in After Period		Empirical Bayes Estimate of Crashes Expected After without Centerline Rumble Strips (Standard Error)		Percent Reduction (95% Confidence Interval)	
Miles	Sites	Crash Type	All	Injury	All	Injury	All	Injury
210.8	98	All	1481	532	1724.0 (39.5)	629.1 (22.7)	14% (8-20%)	15% (5-25%)
		Frontal/Opposing-Direction	147	81	186.5 (10.5)	106.7 (7.7)	21% (5-37%)	25% (5-45%)

(Source: Persaud, Retting, and Lyon 2003)

The statistical results of the studies by regression to the mean methods show more generous effects caused by the implementation of centerline rumble strips. Therefore, the empirical Bayes estimates are conservative calculations of the efficiency of centerline rumble strips. As exciting as it might be to report large reductions in cross-over collisions, it is ultimately safer to underestimate the safety enhancements that centerline rumble strips have on rural two-lane undivided highways. However, the effectiveness of centerline rumble strips is not diminished. After centerline rumble strips were installed, all crash types experienced a significant reduction in occurrences according to the empirical Bayes model. But what is more impressive is that frontal and opposing direction sideswipe crashes were reduced by a greater percentage than the total crash rate reduction. This is evidence that centerline rumble strips have reduced the frequency of cross-over collisions.

The UDOT/BYU state of the practice was designed to include various data types that could be cross examined. However, the amount of data received provided insufficient evidence to create any correlations between centerline rumble strip geometry, cost, and safety.

4.1.3. Improved Safety in Low Visibility Driving Conditions

Driving in low visibility conditions is not desirable. Unfortunately, various entities require the transporting of goods or services regardless of the road conditions. The survey participants were asked if they were driving in poor road visibility conditions, would the presence of centerline rumble strips help them stay in their lanes. The response was strongly in favor of centerline rumble strips to help drivers stay in their lanes when visibility is limited (see Table 14).

Table 14: Frequency Results of Question 10 of the Public Opinion Survey

CLRS Aid Driving in Low Visibility	Survey Response	Percent Response	Cumulative Percent
Strongly Agree	241	45%	45%
Agree	199	37%	83%
No Opinion	65	12%	95%
Disagree	16	3%	98%
Srongly Disagree	10	2%	100%
Missing	2		

An overwhelming response to use centerline rumble strips as an aid in poor visibility conditions was voiced by large truck drivers. Only one heavy truck driver admitted to not using centerline rumble strips as a form of lane delineation in poor visibility conditions.

Typically, the effectiveness of pavement markings decreases in the rain and at night. Painting the pavement markings directly over the rumble strips may improve marking visibility in these conditions. A report analyzing the effects of creating a profiled pavement marking system by painting the markings over milled rumble strips had significant results. “Retroreflectivity measurements for dry and wet-night conditions are significantly higher for milled rumble strip edge line markings as compared to standard edge line markings" (Filcek et al. 2004) (see Figure 8). The improvement in the reflective visibility from installing the pavement markings over the milled rumble strips is another way that the safety of driving in poor visibility conditions may be improved.

Figure 7: Dry-night Retroreflectivity of Pavement Markings on Rumble Strips
(Source: Filcek et al. 2004)

Figure 8: Wet-night Retroreflectivity of Pavement Markings on Rumble Strips
(Source: Filcek et al. 2004)

The public opinion survey attempted to duplicate the results of the profiled pavement marking report (Filcek et al. 2004) by driver observations of pavement markings over the centerline rumble strips. The survey question asked drivers whether the double yellow lines were more visible when painted over the rumble strips than on flat pavement. The descriptive statistics of this question were not conclusive as most participants responded with no opinion. However, a greater percentage of surveys agree that pavement markings are more visible over centerline rumble strips than disagree (see Table 15).

Table 15: Frequency Results of Question 13 of the Public Opinion Survey

Markings Over CLRS Improve Lane Markings	Survey Response	Percent Response	Cumulative Percent
Strongly Agree	36	7%	7%
Agree	161	30%	37%
No Opinion	254	48%	85%
Disagree	66	12%	98%
Strongly Disagree	13	2%	100%
Missing	3		

4.2. Cost Effective Technology

In direct correlation to safety, cost is a significant influencing factor effecting the installation of centerline rumble strips. Overhead costs of centerline rumble strips include the cost of installation and maintenance. Cost effectiveness may be derived from incurred costs and assumed costs of damage, injuries or fatalities. Multiple concepts of maximizing the cost effectiveness of centerline rumble strip installations exist.

4.2.1. Low Installation Costs

One of the strongest arguments for centerline rumble strips is the cost of installation. Many State departments of transportation, if not all of them, are subject to similar circumstances when faced with the responsibility of improving highway safety. ODOT District Manager, Don Jordan said, “Usually, that means installing a metal guard rail, a concrete barrier, or even building a divided highway. Unfortunately, all those improvements cost money that ODOT just doesn’t have” (Davis 2002).

Various pieces of literature have reported costs of centerline rumble strips. In a recent study, reported installation costs ranged from a low of $0.05 per linear foot to a high of $1.50 per linear foot (Turochy 2004). The report did not specify if these costs included incidentals to centerline rumble strips such as debris clean-up, labor wages, or worksite traffic control. The low price occurred for a bid project of 1600 linear miles of rumble strip installation for $280 per linear mile (Turochy 2004).

The same report indicated that 26 percent of states reported values less than or equal to $0.10 per linear foot. The Delaware department of Transportation published brochures in 2001 explaining the success and benefits of centerline rumble strips. The handout includes a phrase saying, “Technological advances have reduced the cost of installing centerline rumble strip to about $0.20 to $0.60 a linear foot depending on the length of installation (Delaware 2001). These costs are significantly lower than the $6.18 per linear meter ($1.88 per linear foot) the New York State Department of Transportation reportedly paid in 1990 for a shoulder rumble strip installation (Perrilo 1998).

The state of the practice survey shows an average cost of installation ranging from $0.15 per linear foot to $2.00 per linear foot. The departments were asked to specify the cost of installation only. If this is accurate, then the cost of installation varies significantly between states. However, these prices may report additional costs such as resurfacing, road closure and traffic maintenance or other potential costs incurred with centerline rumble strip installations.

Additional benefits with respect to the cost of certain improvements, the AASHTO/NCHRP website further comments on the relatively low cost of centerline rumble strips, stating "This low cost strategy does not involve reconstruction and would not involve the environmental process or right-of-way acquisition… Incorporation of centerline rumble strips as part of an agency's design practice for new construction or resurfacing can occur quickly (within 1 year)" (NCHRP Objective 18).

4.2.2. High Cost Efficiency

Centerline rumble strips have minimal requirements restricting their installation. This is advantageous for departments that need to address cross-over crashes quickly and do not have excessive amount of funds at their disposition. When the results of how centerline rumble strips effectively increase undivided highway safety are compared to the low costs of installation, the cost effectiveness of rumble strips is recognizably high.

Benefit to cost ratios of centerline rumble strips have been reported as low as 10:1 (Hirasawa, Asano, and Saito 2004). Delaware estimated the benefit-to-cost ratio of the Highway US-301 installation to be 110:1(Delaware 2002). The benefit-to-cost ratio of shoulder rumble strips is reported as high as 182:1. The Nevada Department of Transportation reported that with a benefit-to-cost ratio of shoulder rumble strips from 30:1 to more than 60:1 are more cost-effective than many other safety features (Missouri Transportation Bulletin 2002). Maine DOT survey of 50 states reported a benefit-to-cost ratio of shoulder rumble strips of 50:1 on rural Interstates nationwide (Missouri Transportation Bulletin 2002). Considering these benefit-to-cost ratios, centerline rumble strips are comparable and similar to shoulder rumble strips in the cost efficiency.

4.2.3. Cost Reduction Techniques

Beyond the basic observation that centerline rumble strips are inexpensive, there are various practices that can be used to reduce the overall cost of their installation. Experience shows that the larger the contract, the lower the cost of installation. Part of the incurred cost is bringing material and equipment to a job site. Therefore the overhead cost of moving equipment proportionately decreases and resulting prices appear to be cheaper per linear foot.

Another approach to minimizing rumble strip installation costs is to have a state wide project to construct rumble strips along all highways. This could be a combined shoulder and centerline rumble strip project. Connecticut saw their unit costs drop by half and eliminated quality control problems simultaneously (Surface Preparation Technologies undated).

It has also been suggested that rumble strip contract be accorded a flexible starting date. Since the relative time to install centerline rumble strips is short compared to other highway related jobs, rolling start dates allow more contractors to bid, hence more competitive bidding takes place. More competitive bidding causes contractors to minimize bid costs. However, once a particular contract is started, companies need to be held to strict installation guidelines to minimize worksite related costs. (Surface Preparation Technologies undated)

4.3. Versatile Installation Conditions

Unlike rolled or formed rumble strips, milled rumble strips may be installed on most pavements and conditions. Milled rumble strips can be installed on existing, new, or reconstructed pavement (Perrilo 1998). Provided the proper equipment, rumble strips may be installed in bituminous or Portland cement concretes.

4.4. Effective Vibrations and Audible Warnings versus Noise

A major dilemma associated with rumble strips is the level of sound required to be effective in improving highway safety while minimizing the noise heard by road side residences and businesses. Conceptually, a louder rumble strip will provide a more effective alert. Unfortunately, the louder the rumble strip, the more noise pollution heard by nearby residents.

4.4.1. Audio-Effective Rumble Strip Design

As stated by Perrilo, “Milled rumble strips are preferred because of their method of installation, their minimal effort on pavement structures and the increased noise and vibrations they produce. Many states that currently use milled rumble strips have historically used rolled rumble strips with varying success” (Perrilo 1998).

The milled rumble strip reflects the interface between the pavement and the tire. The average size of a milled rumble strips has a seven inch longitudinal length and one-half inch depth. The concave shape of the milled rumble strip with these dimensions has a 12 inch radius. This 12 inch radius is comparable in size to most of the tires on the roads. Likewise, most tires on the highways are narrower than 12 inches or 16 inches. In combination, these dimensions permit a tire to descend into the groove, resulting in an approximate one-half inch vertical displacement of the tire. The repetitive displacement of the tire as it is driven over multiple rumble strip grooves is the cause of the vibration felt by the vehicle. Consequently, that is the difference between the effectiveness of milled rumble strips and rolled or formed rumble strips. Generally, the grooves of milled rumble strips are shallower than the grooves of rolled and formed rumble strips. However, a tire cannot displace into the rolled or formed grooves because of insufficient length in the rumbles. “The resulting (rolled rumble strip) tire drop is approximately 0.76 mm (0.03 in), which is approximately 1/26 of the resulting vertical tire drop of the milled rumble strips” (Perrilo 1998). The ratio of resulting tire drops of rolled rumble strips should be approximately 1/16 of the milled rumble strips. Regardless of the ratio, the difference between the two drops is significant.

The Russell, Rys, and Brin study (2003), sponsored by the Kansas Department of Transportation, conducted a multi-pattern test with multiple vehicles. The nature of this test was to determine which patterns made the most effective decibel readings for a particular vehicle type. There were 12 patterns tested (see Table 16).

Table 16: Dimensions of KDOT Spacing Field Test

Section	Pattern	Spacing (in)	Width (in)
1	Continuous	12	16
2	Continuous	24	16
3	Alternating	12-24	16
4	Continuous	12	12
5	Continuous	24	12
6	Alternating	12-24	12
7	Continuous	12	8
8	Continuous	24	8
9	Alternating	12-24	8
10	Continuous	12	5
11	Continuous	24	5
12	Alternating	12-24	5

(Source: Russell and Rys 2005)

There were seven vehicles used in this test. Two large trucks (a 1996 International Harvester 4900 DT 466 dump truck and a 1995 Ford L8000 dump truck), a full-size pickup truck (1991 Chevrolet 2500), a full-size passenger car (1993 Pontiac Bonneville), a compact passenger car (1994 Ford Escort Wagon), a minivan (1995 Ford Aerostar), and a sport utility vehicle (1997 Jeep Cherokee).

The average decibel level for each vehicle traveling at was calculated for each of the 12 test sections. In spite of inconsistent data, the continuous 12 inch on center pattern produced the highest averages (82.0 dB to 94.1 dB). The alternating pattern produced the second highest decibel level range (80.0 dB to 93.3 dB). The 24 inch on center pattern produced the lowest decibel level range (79.0 dB to 92.2 dB). Therefore, shorter rumble strip spacing or higher frequency patterns produce higher volumes from centerline rumble strips.

However, the alternating patterns produced the highest decibel levels in four of the vehicles and second highest in two of the vehicles. The 12 inch on center pattern was the second and the 24 inch on center pattern was last based on individual vehicle average decibel levels.

Either the 12 inch on center pattern or the alternating 12 inch and 24 inch pattern is recommended for use as centerline rumble strips.

The length of the rumble strip perpendicular to the lane direction had little effect. It was noticed that large tires do not produce significant decibel levels when the transverse length is small. It may be assumed that the tires to not fully drop into the rumble strip (Russell, Rys, and Brin 2003).

A study conducted in Japan compared the depth of the groove to the decibel generation of a tire driving over the rumble strips and driver perceived control of different vehicles. The radius of the milling machine was constant, therefore the lengthwise width of the grooves changed. The resulting spacing was constant at approximately 303 mm (12 in) on center (see Table 17). The transverse width of the test strips were controlled as well at a constant 350 mm (14 in).

Table 17: Dimensions of Japanese Depth Field Test

Dimension, mm (in)	Pattern 1	Pattern 2	Pattern 3
Transverse Width	350 (14)	350 (14)	350 (14)
Lengthwise Width	127 (5)	147 (6)	163 (6.5)
Spacing	175 (7)	155 (6)	139 (5.5)
Depth	9 (3/8)	12 (1/2)	15 (9/16)

(Source: Hirasawa, Asano, and Saito 2004)

Table 18 shows the relationship between vehicles speed, depth of the groove and decibel level created by the vehicle-rumble strip interaction of the previous dimensions. This test varied the depth of the rumble strip grooves while maintaining an equal center to center spacing. The observed pattern shows that as the depth of the groove increases, the corresponding decibel level increases.

Table 18: Noise Measurement Inside a Compact/Lightweight Vehicle

	Depeh			
Speed	0 mm	9 mm	12 mm	15 mm
40 km/h	62 dB	75 dB	77 dB	80 dB
60 km/h	63 dB	78 dB	81 dB	84 dB
80 km/h	64 dB	80 dB	83 dB	85 dB
100 km/h	66 dB	85 dB	91 dB	94 dB

(Source: Hirawasa, Asano, Saito, 2004)

4.4.2. Noise Pollution and Complaints

Much like shoulder rumble strips, one of the greatest concerns of centerline rumble strips is the side effects of noise to roadside residences and business. The previous two field tests represent quantified values of decibel levels produced by vehicle interaction with rumble strips. However, these tests attempt to maximize the decibel levels for the purpose of safety. There has been no research attempting to maintain the effective sound levels of centerline rumble strips while responding to the excess noise concerns of highway-side residents or businesses.

The approach to remediation of noise pollution varies dramatically between states. the options fronted by the various states include:

- Avoid placement of rumble strips in populated locations unless crash data, shows a high potential for crash reduction in that specific area,
- Build sound-wall construction,
- Use shallower installation depths,
- Use centerline rumble strips in no passing zones,
- Inform residents prior to installation, but no efforts being made to reduce noise,
- Run centerline rumble strips continuously past driveways as safety devices, that is, impose no restrictions.

Currently, avoiding the placement of rumble strips in populated areas is the only way to eliminate noise. Using sound-walls, reducing the rumble strip depth, limiting installations to no passing zones are methods of limiting the excess noise generated by rumble strips.

Pennsylvania observed that in contacting road side residents prior to installing rumble strips that the residents often times prefer having noise than crashes near their home. This corresponds well with the approach used by Minnesota. Minnesota installs rumble strips continuously regardless of the presence of roadside residents.

However, these approaches downplay the seriousness of noise pollution. The states of Connecticut and New Jersey have decided as a state to not install rumble strips. Connecticut’s decision lies explicitly with noise complaints. New Jersey’s choice is split between noise complaints and pavement deterioration issues.

4.5. Public Approval

Important to a government agency is the approval of its supporting public. There is little purpose in pursuing a technology that the public does not want. The public opinion survey addressed this issue. The last question of the survey asked if the State of Utah should use centerline rumble strips (see Appendix A). The results of this survey show strong support for the continued installation of centerline rumble strips in the State of Utah by a 7:1 ratio (see Table 19).

Table 19: Frequency Results of Question 14 of the Public Opinion Survey

Install More CLRS	Survey Response	Percent Response	Cumulative Percent
Yes	438	87%	87%
No	63	13%	100%
Missing	32		

Further analysis of the public opinion survey showed an interesting pattern. A Chi-square analysis was conducted comparing this question to all others. Fourteen of the twenty-two question returned significant results ($P \leq 0.05$). The interesting results surfaced as each analysis was compared to the next. Besides the tables comparing question 1 to question 14 and comparing question 6.1 to question 14, the remaining tables follow the same pattern. This pattern is if a participant favored the installation of centerline rumble strips (i.e. answered "Yes" to question 14) they generally responded to positive traits that centerline rumble strips may have. Positive traits may be increased safety or increased confidence. Contrary to this, participants that do not favor future installation of centerline rumble strips generally responded that centerline rumble strips did not have any desirable traits. From this, we may conclude that drivers want more centerline rumble strips because they feel that centerline rumble strips offer increased safety, improved lane delineation even at the cost of potentially irritable noises and disruptions while driving.

4.5.1. Positive Reaction to Centerline Rumble Strips

The behavior of a driver varies dramatically between driving attentively opposed to driving inattentively. The conscious, alert and attentive driver is aware of their vehicle and other vehicles on the road. Contrarily, the inattentive driver is less concerned with their vehicle or other vehicles on the road. The inattentiveness of a driver is dangerous and may be a significant cause of crossover crashes.

The presence of centerline rumble strips as a safety enhancement also results in drivers incidentally contacting them. There are many emotions that may develop from this event. Question 6.3 and question 6.4 attempt to generalize the resulting feelings of drivers that contact the centerline rumble strips. Question 6.3 addresses the reaction to centerline rumble strips while drivers are alert. Question 6.4 addresses the reaction to centerline rumble strips if drivers are drowsy or asleep (see Appendix A for these questions).

A significant majority of those surveyed responded that they would react positively to contacting centerline rumble strips if they were driving alertly. And, even more of those surveyed would react positively to contacting centerline rumble strips if they were drowsy or asleep. This result is not surprising. The ability of rumble strips to restore alertness to a driver is the key element in the success of rumble strips. If the potential of a crash increases, it appears that a driver is ultimately grateful for the presence of rumble strips to counter that potential crash. The frequency results follow.

Table 20: Frequency Results to Question 6.3 of the Public Opinion Survey

Reaction Type	Survey Response	Percent Response	Cumulative Percent
Positive	329	63%	63%
Neutral	144	27%	90%
Negative	52	10%	100%
Missing	8		

Table 21: Frequency Results of Question 6.4 of the Public Opinion Survey

Reaction Type	Survey Response	Percent Response	Cumulative Percent
Positive	447	85%	85%
Neutral	47	9%	94%
Negative	34	6%	100%
Missing	5		

Age has an effect on the reaction of drivers to contact with centerline rumble strips while alert. A statistically significant observation ($p \leq 0.05$) is that younger drivers expressed greater neutrality than older drivers. This could signify that older drivers are more appreciative of the improvements. Other interpretations could include younger drivers are more agitated by the incidental contact with the rumble strips but still grateful to have some sort of warning.

4.5.2. Improved Driver Confidence

Introducing another element to the highway has the potential to alter the behavior of drivers. The same is true when centerline rumble strips are installed.

Participants of the public opinion survey were asked if they were more confident of their vehicle's location on the road and other drivers' vehicles location on the road with centerline rumble strips than without centerline rumble strips. The response to this question shows that drivers are more confident with centerline rumble strips than without.

Table 22: Frequency Results of Question 8 of the Public Opinion Survey

CLRS improves Driver Confidence	Survey Response	Percent Response	Cumulative Percent
Strongly Agree	83	16%	16%
Agree	266	50%	66%
No Opinion	119	22%	88%
Disagree	49	9%	98%
Strongly Disagree	13	2%	100%
Missing	3		

Statistical analysis via a Chi-square of age versus driver confidence with the presence of centerline rumble strips provided a statistically significant relation with a greater than 95 percent confidence ($p \leq 0.05$). The analysis shows that younger drivers are less inspired by the presence of centerline rumble strips than older drivers. In other words, older drivers feel an increase in confidence when centerline rumble strips are installed and more confident than younger drivers.

Installing centerline rumble strips on roads that have shoulder rumble strips already installed creates another issue. Having the warning measure on both sides of the driver may create an entrapped feeling. Therefore, in addition to the previous question, drivers were asked how their confidence would increase if both centerline and shoulder rumble strips were present compared to their confidence if only shoulder or centerline rumble strips were present. The frequency results reveal that drivers again would be more confident of their vehicle position with both measures installed.

Table 23: Frequency Results of Question 8.1 of the Public Opinion Survey

CLRS and SRS Improve Driver Confidence	Survey Response	Percent Response	Cumulative Percent
Strongly Agree	64	12%	12%
Agree	271	52%	64%
No Opinion	120	23%	87%
Disagree	55	10%	97%
Strongly Disagree	14	3%	100%
Missing	9		

The results of a comparative analysis of age and the confidence of drivers with centerline rumble strips and shoulder rumble strips mimic the results of the previous comparison. These results were statistically significant to a 95 percent confidence level. Again, older drivers feel more confident with both types of rumble strips present compared to younger drivers.

4.6. Maintenance

The required maintenance for centerline rumble strips is notably minimal. One of the selling points of centerline rumble strips is that it requires little maintenance. However, maintenance is still a concern. The issues associated with centerline rumble strip maintenance include the premature deterioration of the pavement and markings, and cleaning the accumulations of debris, snow and sand in the grooves.

Pavement deterioration may be enhanced by the milling of the rumble strips along the pavement joint between lanes or abrasive contact form equipment such as snowplows (Alaska 2001). Some reports state that rumble strips appear to have a detrimental effect on the life of the pavement (Outcalt 2001; Alaska 2001). Other reports mention little or no effect on pavement quality (Turochy 2004; Delaware 2002; Noyce and Elango 2004). Since centerline rumble strips are relatively new, “the durability of rumble strips are not yet known, but they are expected to have a service lifespan of at least 10 years because they are installed where wheels usually do not pass” (Hirasawa, Asano, and Saito, 2004). The cause of the deterioration is undetermined yet assumed to be closely associated with the other maintenance issues of centerline rumble strips.

Centerline rumble strips accumulate debris, sand and snow. “The milled rumble strip centerlines on M-13 in Bay County are also subjected to filling with dirt, road salt and slush. Wind velocity created by passing vehicles is apparently insufficient in keeping the centerline grooves dry and clean. This is probably due to lower traffic speeds and opposing traffic flows in the recessed areas of the center of the highway” (Filcek et al. 2004). This is complicated by slow traffic. Rumble strips may fill with snow and ice in areas with low traffic speeds. Filcek et al (2003) also reported that milled rumble strips increase the durability of the pavement markings by protecting the binder and glass beads from the snowplows.

4.7. Vehicle Operation Concerns

The vibration of centerline rumble strips has potential negative effects on the operational abilities of bicycles, motorcycles, and emergency vehicles.

A considerable amount of information has been published on the effects of shoulder rumble strips on bicyclists. Various opinions have been proposed to accommodate bicyclists and maintain shoulder rumble strip installations. By observation, centerline rumble strips have less of an effect on bicyclists than shoulder rumble strips since bicyclists ride on the shoulders of highways.

There is an indirect negative effect caused by centerline rumble strips on bicycles. As observed in the Noyce and Elango report, vehicles laterally displace away from centerline rumble strips (Noyce and Elango 2004). The vehicle encroaches on the shoulder of the road. This crowds a bicyclist riding on the shoulder. Furthermore, Bicycle Colorado expressed concerns that motorists are less likely to cross the centerline to give space to cyclists if centerline rumble strips are present. This combination creates a hazardous situation for bicyclists. Therefore, “various bicycle advocates in Colorado are opposed to CLRS on two-lane, mountain roads with no shoulders. According to Bicycle Colorado (2002) (info@bicyclecolo.org, unpublished data) they cite the Davis study and claim 400 letters opposed the planned milling of CLRS on two canyon roads" (Russell, Rys, and Brin 2003).

There is a fear that riding bicycles and motorcycles on milled rumble strips will cause the cycle to lose control. "One state noted that a motorcyclist had hit the rumble strips and lost control of the motorcycle" (Turochy 2004).

However, there have been some field tests conducted revealing the effects of milled rumble strips on vehicles. A Canadian test reported 'motorcycles encountered no adverse handling conditions when riding on or over rumble strips except when braking. Which was not an issue since it was unlikely that deceleration would occur entirely within the rumble strip zone" (Transportation Association of Canada (TAC), Synthesis of Practice Report, 2001, cited in Russell, Rys, and Brin 2003).

The video recording made in a Japanese study did not reveal any dangerous driving or riding, such as sudden braking, sudden steering or falling (Hirasawa, Asano, and Saito 2004)

The public opinion survey provided a bicycle and a motorcycle option to the survey participants. However, the number of participants in the survey who said they ride motorcycles or bicycles on highway U.S. 6 was minimal. There were only four bicyclists and 16 motorcyclists out of 533surveys.

Vehicular control is affected in two ways. A vehicle may lose control if the driver steers the vehicle too aggressively. A vehicle may also lose control if the driving surface provides inadequate traction. The traction of the vehicle may be affected by rumble strips.

In consideration of these possibilities, the survey asked drivers whether centerline rumble strips will affect the control of a vehicle. Question 6.5 addresses how drivers might steer their vehicle if they came in contact with centerline rumble strips. Slightly less than 23 percent of drivers feel that driving on centerline rumble strips will cause them to steer dangerously to correct the vehicle. Thus, this question favors the opinion that centerline rumble strips to not cause drivers to steer dangerously (see Table 24).

Table 24: Frequency Results of Question 6.5 of the Public Opinion Survey

CLRS Cause Dangerous Driving	Survey Response	Percent Response	Cumulative Percent
Strongly Agree	50	9.4%	9.4%
Agree	70	13.2%	22.5%
No Opinion	153	28.8%	51.3%
Disagree	146	27.4%	78.7%
Strongly Disagree	113	21.2%	100.0%
Missing	1		

Question 11 differs from the previously analyzed question in that the resulting danger is not a result of the driver's behavior but caused by the vehicle's contact with the driving surface. The frequency results report that drivers believe that rumble strips do not cause a significant loss of vehicle control. These results include the opinions of the bicyclists and motorcyclists.

Table 25: Frequency Results of Question 11 of the Public Opinion Survey

CLRS Cause Loss of Vehicle Control	Survey Response	Percent Response	Cumulative Percent
Strongly Agree	35	7%	7%
Agree	35	7%	13%
No Opinion	97	18%	32%
Disagree	125	24%	55%
Strongly Disagree	237	45%	100%
Missing	4		

Considering both of these questions, it may be concluded by the opinion of drivers that centerline rumble strips do not decrease road safety by reducing vehicular control.

4.8. Vehicle Corrections and Driver Reactions

The centerline rumble strip was generated from the success of shoulder rumble strips. Two specific issues of centerline rumble strips result from shoulder rumble strips. Since shoulder rumble strips have been widely used across the United States for many years, drivers have become familiar with them. Centerline rumble strips are relatively new compared to shoulder rumble strips. The design of centerline rumble strips is similar to shoulder rumble strips. Therefore, it is possible that drivers will react to centerline rumble strips as if they were shoulder rumble strip by correcting the vehicle to the left. The second issue is that shoulder rumble strips are supplemented by additional shoulder space where a driver can react to the rumble strips and correct the vehicle. Centerline rumble strips provide a warning to the driver but no additional space to correct the vehicle without entering the oncoming lane.

4.8.1. Correcting the Vehicle into the Oncoming Lane

In a report by Noyce and Elango (2004), the steering patterns of research participants that suddenly contacted rumble strips were analyzed. The goal of their research was to determine if drivers would react adversely to contacting centerline rumble strips by steering to the left. This would effectively place the cross-over vehicle farther into the lane of oncoming traffic.

Test results showed approximately 27 percent of drivers making initial left turns. However, it appeared that, with experience, drivers were quicker to return to the appropriate travel lane. (Noyce and Elango 2004)

The following questions of the public opinion survey are dependent upon the experience of the driver. If the driver has not driven on centerline rumble strips, how could the driver express an informed opinion about the effects of the centerline rumble strips? Shoulder rumble strips have existed longer than centerline rumble strips. They are placed on divided and undivided highways. This increases the probability that a driver has contacted shoulder rumble strips. Having experienced shoulder rumble strips at least, provides a driver with a relative perception of how centerline rumble strips function.

Therefore, to validate comparative responses to the questions 6.1 and 6.2, the survey participants were asked what sort of rumble strips they have driven on. The frequency results of question 6 may be found in Table 26.

Table 26: Frequency Results of Question 6 of the Public Opinion Survey

Rumble Strip Type	Survey Response	Percent Response	Cumulative Percent
Centerline Only	46	9%	9%
Shoulder Only	93	18%	27%
Both Types	347	68%	96%
None	22	4%	100%
Missing	25		

Centerline rumble strips effectively warn drivers when they are encroaching on the centerline. This is a difficult thing to avoid for larger vehicles, especially trailers that track inside the path of the semi truck towing the trailer. Comparative analysis shows that small cars hit both types of rumble strips less frequently than larger vehicles. Compact cars have a large contribution to the drivers that have not experienced both types of rumble strips. Opposing the results of the compact car is that of the heavy truck. Nearly all of the heavy truck drivers report contact with both centerline and shoulder rumble strips.

In response to the Noyce and Elango report, survey participants were asked two questions. The first question asked if they felt the warning created by contacting centerline rumble strips was easily distinguished from those of shoulder rumble strips. The majority of drivers feel that centerline rumble strips provide a distinct warning comparable to shoulder rumble strips. If such is the case, the potential for drivers to properly correct their vehicles would increase. These results appear to support the results of the Noyce and Elango report. The results of question 6.1 are listed in the Table 27.

Table 27: Frequency Results of Question 6.1 of the Public Opinion Survey

Different Warning	Survey Response	Percent Response	Cumulative Response
Strongly Agree	66	19%	19%
Agree	104	30%	50%
No Opinion	86	25%	25%
Disagree	63	18%	43%
Strongly Disagree	24	7%	7%
Missing	7		

However, there are controlling variables, such as alertness when the driver hit the rumble strips and experience with driving on roads with centerline rumble strips that the Noyce and Elango report were able to address that this survey could not control. Therefore, if the warning of centerline rumble strips in actuality is not easily differentiable from shoulder rumble strips drivers may steer farther into the path of oncoming traffic before correcting their vehicle to their own lane. This may ultimately change the reliability of the frequency results of this question.

Complimentary to the frequency results of question 6.1, a Chi-square analysis of heavy truck drivers and the same question reveal a strong agreement that the warnings of the two types of rumble strips are different (significance greater than 95 percent confidence). However, this analysis was based upon the entire sample and not only those that have experienced both types of rumble strips.

In addition to question 6.1, question 6.2 asked if centerline rumble strips should have a distinct warning versus the warning of shoulder rumble strips. The results of this question are dependent on whether the driver has experienced both types of rumble strips. A large portion of the participants answered “No Opinion” to question 6.2. Beyond this, a small majority of the surveys reported favorable to making centerline rumble strip warnings different from shoulder rumble strips. Unfortunately, from this survey, the frequency results are inconclusive concerning the need to have distinct warning between that of centerline rumble strips and of shoulder rumble strips (see Table 28).

Table 28: Frequency Results of Question 6.2 of the Public Opinion Survey

Should be Different	Survey Response	Percent Response	Cumulative Percent
Strongly Agree	37	11%	11%
Agree	99	29%	39%
No Opinion	121	35%	74%
Disagree	78	23%	97%
Strongly Disagree	11	3%	100%
Missing	4		

Chi-square analysis of each of the demographics compared to question 6.2 provided no significant difference.

4.8.2. Lateral Space for Vehicle Correction

Most centerline rumble strip installations are in a single row pattern (see Appendix C: Figure 1 for schematic drawing). Consider the following information. If a vehicle drifts at approximately three degrees at highway speeds, a 12 inch to 16 inch wide rumble strip will provide the tires and vehicle with less than one second of sound and vibration while completely crossing the rumble strip (Alaska 2001). A study comparing the results of multiple braking reaction times and driver steering reaction times reported that an average braking reaction time of 1.25 seconds, for surprise intrusions a reaction time of 1.5 seconds and an average steering reaction time of about 0.3 seconds faster than the average breaking reaction time (Green 2000). These numbers give an approximate steering reaction time of 0.95 seconds if alert. However, if a driver has fallen asleep, the reaction time may be better represented by the surprise intrusion reaction times. In the time that a driver reacts to shoulder rumble strips, the right-side tires of the vehicle have crossed the rumble strips and are on the shoulder of the road. If the time that a vehicle spends on a centerline rumble strip groove is comparable or less than the reaction time of the driver, at the instant the driver begins to correct the path of the vehicle, the left-side tires of the vehicle will be in the opposing lane. The concept of double row centerline rumble strip patterns with a paved median would provide additional space for drivers to correct their vehicles without entering the opposing lane.

The public opinion survey addressed the available reaction time of drivers on a single row installation. Question 7 of the public opinion survey asked drivers if they were to fall asleep and drift onto the centerline rumble strips, would they have enough time to awake, react and safely steer their vehicle back into their own lane without entering the oncoming lane. The intention of this question was to discover the drivers’ level of confidence in the single row pattern. Most of the drivers believed that they would be able to accomplish these requirements. There are many that were uncertain whether the single row pattern would be adequate to provide enough return time and space.

Table 29: Frequency Results of Question 7 of the Public Opinion Survey

Sufficient Time	Survey Response	Percent Response	Cumulative Response
Strongly Agree	84	16%	16%
Agree	205	39%	55%
No Opinion	175	33%	88%
Disagree	37	7%	95%
Strongly Disagree	26	5%	100%
Missing	6		

In an effort to verify these responses, drivers were asked a supplementary question. Question 7.1 asked if the driver has ever fallen asleep and drifted onto the centerline rumble strips. Only 37 drivers of the entire survey said that they had fallen asleep. Most of these drivers reported that a single row pattern provided enough reaction time and space to return their vehicle safely to the proper lane. Unfortunately, the limited number of responses returned insignificant results (significant to less than 95 percent confidence).

Table 30: Frequency Results of Question 7.1 of the Public Opinion Survey

Fallen Asleep and Driven on to CLRS	Survey Response	Percent Response	Cumulative Response
Yes	37	9%	9%
No	363	91%	100%
Missing	133		

A comparison of question 7 and question 9 revealed a diagonal relationship in the Chi-square table (statistically significant at greater than 95 percent confidence, $P < 0.0001$). Question 9 asked if centerline rumble strips significantly reduce head-on collisions caused by drivers crossing the centerline. The strong trend shows that if someone agrees with the requirements in question 7, they feel the same about question 9. This means that if someone feels single row centerline rumble strips provide adequate reaction time to drivers, they also believe that centerline rumble strips will reduce head-on collisions. However, and perhaps more importantly, if a driver feels that the single row pattern of centerline rumble strips provides insufficient reaction time, they will also believe that a single row design is not effective at reducing cross-over crashes.

A more complex approach to centerline rumble strips involves placing a buffer zone median between two rows of rumble strips (see Figure 9). This median is similar to a two-way left turn lane. The idea is to provide extra space where the driver can correct the vehicle after being stimulated by the rumble strips. This also lowers the chance that a driver has of entering the oncoming traffic lane.

The survey participants were provided the following two pictures (see Figure 9).

Figure 9: Photos of Highway SR-91 near Brigham City, Utah (Double Row Pattern) and Highway US-6 near Spanish Fork, Utah (Single Row Pattern)
(Photos by Sam Richards 2004)

Question 9.1 asked drivers if they felt that using centerline rumble strips with a paved median be preferred over a single row pattern to improve safety. Similar to the results of question 7, most drivers agreed that the double row pattern would increase safety but there is a large portion of the participants that expressed no opinion.

Table 31: Frequency Results of Question 9.1 of the Public Opinion Survey

Double Row for Safety	Survey Response	Percent Response	Cumulative Response
Strongly Agree	119	23%	23%
Agree	183	36%	59%
No Opinion	159	31%	90%
Disagree	25	5%	95%
Strongly Disagree	26	5%	100%
Missing	21		

The Chi-square analysis of question 7 and question 9.1 was not as clear as the previous comparison of question 7 and question 9. However, the trend established by resembles an “X” (see Appendix B).The problem with such a result is that no dominant relationship is available. Therefore, from this analysis, a definite conclusion cannot be made.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1. Summary

Centerline rumble strips have been reviewed by three different methods. The literature review of centerline rumble strips revealed that there are advantages and disadvantages to centerline rumble strips. The public opinion survey focused on further installations of centerline rumble strips in the State of Utah. The state of the practice survey gathered usage, geometric, cost and crash data of state departments of transportation across the United States.

Future installations of centerline rumble strips in the State of Utah should be pursued. The published literature on centerline rumble strips demonstrates a low cost method of cross-over crashes on rural, two-way, undivided highways. Even though the current before and after crash data is less convincing when analyzed by more robust statistical analysis methods, the data still shows a reduction in cross-over crashes. Other advantages of centerline rumble strips are the low cost of installation, minimal maintenance costs, and improved lane delineation.

5.2. Findings

The literature exposes numerous issues associated with centerline rumble strips. A lack of after data decreases the statistical confidence in the ability of centerline rumble strips to reduce crossover crashes. Noise pollution complaints from roadside residents have been reason enough to for some states to not install centerline rumble strips. Pavement deterioration, bicycle and motorcycle safety concerns, and emergency vehicle operation issues have partial solutions but remain unresolved.

The public opinion survey provided statistical evidence of support for centerline rumble strips on rural, two-way, highways. Statistical evidence implies that centerline rumble strips improve perceived safety and driver confidence. Centerline rumble strip road signs increase driver awareness of centerline rumble strips.

The design of the state of the practice survey was to compare the dimensional practices of centerline rumble strips with the crash data and cost of installation and maintenance. The survey was successful in compiling data. National trends for the usage of centerline rumble strips were established. There was insufficient crash data to make a correlation with centerline rumble strip geometry.

5.3. Recommendations

The data acquired by these various methods was used to model a guidelines draft for centerline rumble strips for the Utah Department of Transportation. A copy of the guidelines draft is available in Appendix E.

In order to resolve the current issues with centerline rumble strips, further research should be conducted in the following areas.

- Methods of reducing excess noise to roadside residences and businesses.
- Modified shapes of milled rumble strips that reduce excess noise while maintaining effective audible warnings and vibrations.
- Modified shapes of milled rumble strips where wind currents and vehicle turbulence permit the cleaning of sand, debris, and snow and maintain effective audible warnings and vibrations.
- Correlations between crash reduction and milled rumble strip geometry;
- Correlations among highway geometry, centerline rumble strips and available reaction time to drifting vehicles. This includes paved median design, multiple row rumble strip installations, lane widths, shoulder dimensions, etc.
- Correlations among highway volumes, probability of cross-over crashes and centerline rumble strips.
- Lateral displacement of vehicles when centerline rumble strips and shoulder rumble strips are present on the same section of road.
- Operational capabilities of emergency vehicles interaction with rumble strips.
- Direct and indirect effects of centerline rumble strips on bicycles and motorcycles.

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APPENDIX A: EXAMPLE OF PUBLIC OPINION SURVEY

CENTERLINE RUMBLE STRIP QUESTIONNAIRE

The Utah Department of Transportation has made some changes to US Route 6. They would like to know the public sentiment about the recent installation of centerline rumble strips. Please answer the questions to this survey by circling the answer that corresponds most accurately to your opinion or feelings. If you have any questions, do not hesitate to ask! This survey is completely anonymous. Participants must be at least 18 years old. Participant rights information and survey information are available at the end of the survey.

1 Your Gender: *Male* *Female*

2 Your Age: *18-25* *26-35* *36-50* *Over 50*

3 What type of vehicle do you regularly drive on highways?
Bicycle *Motorcycle* *Compact Car* *Car/Wagon* *SUV/Truck* *Heavy Truck*

4 How often do you drive highway US-6 (through Spanish Fork Canyon between Spanish Fork and Price, Utah)?
Daily/Commuter *1-2 times per week* *1-2 times per month* *1-11 times per year* *Never*

5 Have you seen any signs on the roadside indicating centerline rumble strips? (see question 5 picture on the back) *Yes* *No*

5.1 If you answered "No" go to question 5.2. If you answered "Yes" to question 5, respond to this statement. Did seeing these roadsigns cause you to look for the centerline rumble strips?
Strongly Disagree *Disagree* *No Opinion* *Agree* *Strongly Agree*

5.2 Are the centerline rumble strips easily located, visible or noticed? *Yes* *No*

6 Identify which rumble strips you have ever driven on: *Centerline* *Shoulder* *Both* ***None***

6.1 Do you think the sound, vibration and feeling of the centerline rumble strips is easily distinguishable from the sound, vibration and feeling of shoulder rumble strips?
Strongly Disagree *Disagree* *No Opinion* *Agree* *Strongly Agree*

6.2 Should the sound, vibration, and/or feel of centerline rumble strips be different from shoulder rumble strips?
Strongly Disagree *Disagree* *No Opinion* *Agree* *Strongly Agree*

6.3 When driving consciously and alertly, how would you react if you drifted onto the centerline rumble strips?
Positively (grateful, relieved, etc.) *Neutral* *Negatively (Irritated, confused, etc.)*

6.4 If you fell asleep while driving, how would you react if you drifted onto the centerline rumble strips?
Positively (grateful, relieved, etc.) *Neutral* *Negatively (Irritated, confused, etc.)*

6.5 Do centerline rumble strips cause drivers to steer dangerously to return their vehicles to their lane?
No *Probably Not* *Unsure* *Probably So* *Yes*

7 If you fell asleep and your car drifted onto the centerline rumble strips, would you have enough time to react, avoid entering the other lane and safely return your vehicle to your own lane?
No *Probably Not* *Unsure* *Probably So* *Yes*

7.1 Have you fallen asleep while driving and drifted onto the centerline rumble strips? *Yes* *No*

8 The sight, sound, or vibration of centerline rumble strips make me feel confident of where I am and other drivers are on the road.
Strongly Disagree *Disagree* *No Opinion* *Agree* *Strongly Agree*

8.1 Centerline rumble strips installed on the same section of road as shoulder rumble strips make me feel more confident of where I am on the road than centerline rumble strips or shoulder rumble strips alone.
Strongly Disagree *Disagree* *No Opinion* *Agree* *Strongly Agree*

9 Do centerline rumble strips significantly reduce head-on collisions caused by drivers crossing the centerline?
No *Probably Not* *Unsure* *Probably So* *Yes*

9.1 (See question 9.1 pictures on the back) Would centerline rumble strips with a paved median be preffered over a single centerline rumble strips to improve safety?
No *Probably Not* *Unsure* *Probably So* *Yes*

10 Assuming poor road visibility conditions, would the presence of centerline rumble strips help drivers stay in their lanes?
No *Probably Not* *Unsure* *Probably So* *Yes*

11 Do centerline/shoulder rumble strips cause a significant loss of vehicle control when contacted?
No *Probably Not* *Unsure* *Probably So* *Yes*

13 Are the double yellow lines more visible when painted over the centerline rumble strips than on flat pavement?
Strongly Disagree *Disagree* *No Opinion* *Agree* *Strongly Agree*

14 Should the State of Utah install more centerline rumble strips on rural, undivided highways? *Yes* *No*

Question 5: Centerline rumble strip road sign. (US-6 east of Spanish Fork, Utah)

Question 9.1:

- Rumble strips with median (SR-91 between Brigham City and Logan, Utah)
- Single centerline rumble strip with double yellow line painted on top. (US-6 between Spanish Fork and Price, Utah)

Thank you for completing this survey! If you have any questions about this survey, you may contact Dr. M. Saito at (801) 422-6326. If you have any questions regarding your rights as a participant in research projects, you may contact Dr. Renea Beckstrand, IRB Chair, BYU, 422 SWKT, Provo, UT 84602, (801) 422-3873, renea_beckstrand@byu.edu.

APPENDIX B: SAS STATISTICAL ANALYSIS OUTPUT

Table B-1: Chi-square Analysis and Statistics of Question 2 (Driver's Age) versus Question 5 (Have you seen any road signs indicating centerline rumble strips?)

Frequency Expected Cell Chi-square Percent		Question 2 Yes	 No	Total
Question 5	**18-25**	61 73.202 2.034 11.984	47 34.798 4.279 9.234	108
	26-35	82 77.947 0.211 16.110	33 37.053 0.443 6.483	115
	36-50	100 104.381 0.184 19.646	54 49.619 0.387 10.609	154
	Over 50	102 89.470 1.755 20.039	30 42.530 3.692 5.894	132
	Total	345	164	509

Statistic	DF	Value	Prob
Chi-Square	3	12.9845	0.0047
Likelihood Ratio Chi-Square	3	13.037	0.0046
Mantel-Haenszel Chi-Square	1	8.219	0.0041
Phi Coefficient		0.1597	
Contingency Coefficient		0.1577	
Cramer's V		0.1597	
Effective Sample Size		509	
Frequency Missing		24	

Table B-2: Chi-square Analysis and Statistics for Question 3C (What type of vehicle do you regularly drive on highways? Compact Car) versus Question 5 (Have you seen any road signs indicating centerline rumble strips?)

Frequency Expected Cell Chi-square Percent		Question 5 Yes	 No	Total
Question 3C	Non-Compact Car	285 275.581 0.322 55.773	122 131.419 0.675 23.875	407
	Compact Car	61 70.419 1.260 11.937	43 33.581 2.642 8.415	104
	Total	346	165	511

Statistic	DF	Value	Prob
Chi-Square	1	4.8985	0.0269
Likelihood Ratio Chi-Square	1	4.7546	0.0292
Continuity Adj. Chi-Square	1	4.3922	0.0361
Mantel-Haenszel Chi-Square	1	4.8889	0.0270
Phi Coefficient		0.0979	
Contingency Coefficient		0.0974	
Cramer's V		0.0979	
Effective Sample Size		511	
Frequency Missing		22	

Fisher's Exact Test

Cell (1,1) Frequency (F)	285
Left-Sided Pr <= F	0.9893
Right-Sided Pr >= F	0.0191
Table Probability (P)	0.0084
Two-Sided Pr <= P	0.0341

Table B-3: Chi-square Analysis and Statistics for Question 3F (What type of vehicle do you regularly drive on highways? Heavy Truck) versus Question 5 (Have you seen any road signs indicating centerline rumble strips?)

Frequency Expected Cell Chi-square Percent		Question 5 Yes	 No	 Total
Question 3F	Non-Heavy Truck	314 322.978 0.250 61.448	163 154.022 0.523 31.898	477
	Heavy Truck	32 23.022 3.502 6.262	2 10.978 7.343 0.391	34
	Total	346	165	511

Statistic	DF	Value	Prob
Chi-Square	1	11.6174	0.0007
Likelihood Ratio Chi-Square	1	15.0299	0.0001
Continuity Adj. Chi-Square	1	10.3595	0.0013
Mantel-Haenszel Chi-Square	1	11.5947	0.0007
Phi Coefficient		-0.1508	
Contingency Coefficient		0.1491	
Cramer's V		-0.1508	
Effective Sample Size		511	
Frequency Missing		22	

Fisher's Exact Test	
Cell (1,1) Frequency (F)	314
Left-Sided Pr <= F	0.0001741
Right-Sided Pr >= F	1
Table Probability (P)	0.0001551
Two-Sided Pr <= P	0.0002342

Table B-4: Chi-square Analysis and Statistics of Question 4 (How often do you drive Highway US-6?) versus Question 5 (Have you seen any road signs indicating centerline rumble strips?)

Frequency Expected Cell Chi-square Percent		Question 5 Yes	 No	Total
Question 4	Daily/ Commuter	23 20.972 0.196 4.536	8 10.028 0.410 1.578	31
	1-2 Times per Week	57 52.093 0.462 11.243	20 24.907 0.967 3.945	77
	1-2 Times per month	97 95.391 0.027 19.132	44 45.609 0.057 8.679	141
	1-11 Times per Year	147 147.483 0.002 28.994	71 70.517 0.003 14.004	218
	Never	19 27.061 2.401 3.748	21 12.939 5.022 4.142	40
	Total	343	164	507

Statistic	DF	Value	Prob
Chi-Square	4	9.5475	0.0488
Likelihood Ratio Chi-Square	4	9.1070	0.0585
Mantel-Haenszel Chi-Square	1	5.6344	0.0176
Phi Coefficient		0.1372	
Contingency Coefficient		0.1360	
Cramer's V		0.1372	
Effective Sample Size		507	
Frequency Missing		26	

Table B-5: Chi-square Table and Statistics of Question 1 (Driver's Gender) versus Question 5.1 (Did seeing these road signs cause you to look for the centerline rumble strips?)

Frequency Expected Cell Chi-square Percent		Question 5.1 Stongly Agree	Agree	No Opinion	Disagree	Strongly Disagree	Total
Question 1	Male	20	78	25	23	0	146
		21.992	76.360	26.879	18.326	2.444	
		0.180	0.035	0.131	1.192	2.444	
		8.368	32.636	10.460	9.623	0.000	
	Female	16	47	19	7	4	93
		14.008	48.640	17.121	11.674	1.556	
		0.283	0.055	0.206	1.871	3.836	
		6.695	19.665	7.950	2.929	1.674	
	Total	36	125	44	30	4	239

Statistic	DF	Value	Prob
Chi-Square	4	10.2341	0.0367
Likelihood Ratio Chi-Square	4	11.7211	0.0196
Mantel-Haenszel Chi-Square	1	0.0908	0.7631
Phi Coefficient		0.2069	
Contingency Coefficient		0.2026	
Cramer's V		0.2069	
Effective Sample Size		239	
Frequency Missing		107	
Warning: 31% of the data are missing.			

Table B-6: Chi-square Analysis and Statistics of Question 2 (Driver's Age) versus Question 5.1 (Did seeing these road signs cause you to look for the centerline rumble strips?)

Frequency Expected Cell Chi-square Percent		Question 5.1 Strongly Agree	Agree	No Opinion	Disagree	Strongly Disagree	Total
Question 2	18-25	3	30	14	4	1	52
		7.909	27.681	9.688	5.932	0.791	
		3.047	0.194	1.919	0.629	0.055	
		1.141	11.407	5.323	1.521	0.380	
	26-35	13	23	21	6	0	63
		9.582	33.536	11.738	7.186	0.958	
		1.219	3.310	7.309	0.196	0.958	
		4.943	8.745	7.985	2.281	0.000	
	36-50	9	48	7	10	0	74
		11.255	39.392	13.787	8.441	1.125	
		0.452	1.881	3.341	0.288	1.125	
		3.422	18.251	2.662	3.802	0.000	
	Over 50	15	39	7	10	3	74
		11.255	39.392	13.787	8.441	1.125	
		1.246	0.004	3.341	0.288	3.122	
		5.703	14.829	2.662	3.802	1.141	
	Total	40	140	49	30	4	263

Statistic	DF	Value	Prob
Chi-Square	12	33.9258	0.0007
Likelihood Ratio Chi-Square	12	35.9598	0.0003
Mantel-Haenszel Chi-Square	1	0.7863	0.3752
Phi Coefficient		0.3592	
Contingency Coefficient		0.3380	
Cramer's V		0.2074	
Effective Sample Size		263	
Frequency Missing		83	
Warning: 24% of the data are missing.			

Table B-7: Chi-square Analysis and Statistics for Question 3C (What type of vehicle do you regularly drive on highways? Compact Car) and Question 6 (Identify which rumble strips you have ever driven on)

Frequency Expected Cell Chi-square Percent		Question 6 Centerline Only	Shoulder Only	Both	None	Total
Question 3C	Non Compact Car	29 36.220 1.439 5.709	76 73.228 0.105 14.961	280 273.228 0.168 55.118	15 17.323 0.311 2.953	400
	Compact Car	17 9.780 5.331 3.346	17 19.772 0.389 3.346	67 73.772 0.622 13.189	7 4.677 1.154 1.378	108
	Total	46	93	347	22	508

Statistic	DF	Value	Prob
Chi-Square	3	9.5184	0.0231
Likelihood Ratio Chi-Square	3	8.5498	0.0359
Mantel-Haenszel Chi-Square	1	2.1111	0.1462
Phi Coefficient		0.1369	
Contingency Coefficient		0.1356	
Cramer's V		0.1369	
Effective Sample Size		508	
Frequency Missing		25	

Table B-8: Chi-square Analysis and Statistics for Question 3F (What type of vehicle do you regularly drive on highways? Heavy Truck) and Question 6 (Identify which rumble strips you have ever driven on)

Frequency Expected Cell Chi-square Percent		Question 6 Centerline Only	Shoulder Only	Both	None	Total
Question 3F	Non Heavy Truck	46 42.921 0.221 9.055	92 86.776 0.315 18.110	315 323.776 0.238 62.008	21 20.528 0.011 4.134	474
	Heavy Truck	0 3.079 3.079 0.000	1 6.224 4.385 0.197	32 23.224 3.316 6.299	1 1.472 0.152 0.197	34
	Total	46	93	347	22	508

Statistic	DF	Value	Prob
Chi-Square	3	11.7154	0.0084
Likelihood Ratio Chi-Square	3	16.8582	0.0008
Mantel-Haenszel Chi-Square	1	7.7100	0.0055
Phi Coefficient		0.1519	
Contingency Coefficient		0.1501	
Cramer's V		0.1519	
Effective Sample Size		508	
Frequency Missing		25	
WARNING: 25% of the cells have expected counts less than 5. Chi-square may not be a valid test.			

Table B-9: Chi-square Analysis and Statistics for Question 3F (What type of vehicle do you regularly drive on highways? Heavy Truck) and Question 6.1 (Do you think the sound, vibration and feeling of the centerline rumble strips is easily distinguishable from the sound, vibration and feeling of shoulder rumble strips?)

	Frequency Expected Cell Chi-square Percent	Question 6.1 Strongly Agree	Agree	No Opinion	Disagree	Strongly Disagree	Total
Question 3F	Non Heavy Truck	84 91.099 0.553 15.970	157 155.901 0.008 29.848	150 144.631 0.199 28.517	74 74.194 0.001 14.068	29 28.175 0.024 5.513	494
	Heavy Truck	13 5.901 8.540 2.471	9 10.099 0.120 1.711	4 9.369 3.077 0.760	5 4.806 0.008 0.951	1 1.825 0.373 0.190	32
	Total	97	166	154	79	30	526

Statistic	DF	Value	Prob
Chi-Square	4	12.9016	0.0118
Likelihood Ratio Chi-Square	4	11.6421	0.0202
Mantel-Haenszel Chi-Square	1	5.6061	0.0179
Phi Coefficient		0.1566	
Contingency Coefficient		0.1547	
Cramer's V		0.1566	
Effective Sample Size		526	
Frequency Missing		7	

Table B-10: Chi-square Analysis and Statistics for Question 3F (What type of vehicle do you regularly drive on highways? Heavy Truck) and Question 6.2 (Should the sound, vibration, and/or feel of centerline rumble strips be different from shoulder rumble strips?)

Frequency Expected Cell Chi-square Percent		Question 6.2 Strongly Agree	Agree	No Opinion	Disagree	Strongly Disagree	Total
Question 3F	Non Heavy Truck	48 48.658 0.009 9.074	141 140.359 0.003 26.654	182 182.467 0.001 34.405	97 97.316 0.001 18.336	27 26.200 0.024 5.104	495
	Heavy Truck	4 3.342 0.129 0.756	9 9.641 0.043 1.701	13 12.533 0.017 2.457	7 6.684 0.015 1.323	1 1.800 0.355 0.189	34
	Total	52	150	195	104	28	529

Statistic	DF	Value	Prob
Chi-Square	4	0.5981	0.0118
Likelihood Ratio Chi-Square	4	0.6595	0.0202
Mantel-Haenszel Chi-Square	1	0.1142	0.0179
Phi Coefficient		0.0336	
Contingency Coefficient		0.0336	
Cramer's V		0.0336	
Effective Sample Size		529	
Frequency Missing		4	

Table B-11: Chi-square Table and Statistics of Question 2 (Driver's Age) versus Question 6.3 (When driving consciously and alertly, how would you react if you drifted onto the centerline rumble strips?)

Frequency Expected Cell Chi-Square Percent		Question 6.3 Positive	Neutral	Negative	Total
Question 2	18-25	47 70.571 7.873 9.004	54 31.172 16.717 10.345	12 11.257 0.049 2.299	113
	26-35	66 73.693 0.803 12.644	41 32.552 2.193 7.854	11 11.755 0.048 2.107	118
	36-50	106 98.050 0.645 20.307	33 43.310 2.454 6.322	18 15.640 0.356 3.448	157
	over 50	107 83.686 6.495 20.498	16 36.966 11.891 3.065	11 13.349 0.413 2.107	134
	Total	326	144	52	522

Statistic	DF	Value	Prob
Chi-Square	6	49.9373	<0.0001
Likelihood Ratio Chi-Square	6	50.7556	<0.0001
Mantel-Haenszel Chi-Square	1	23.6959	<0.0001
Phi Coefficient		0.3093	
Contingency Coefficient		0.2955	
Cramer's V		0.2187	
Effective Sample Size		522	
Frequency Missing		11	

Table B-12: Chi-square Analysis and Statistics for Question 2 (Driver's Age) and Question 8 (The sight, sound, or vibration of centerline rumble strips make me feel confident of where I am and other drivers are on the road.)

Frequency Expected Cell Chi-square Percent		Question 8					
		Strongly Agree	Agree	No Opinion	Disagree	Strongly Disagree	Total
Question 2	18-25	14 18.205 0.971 2.657	51 58.611 0.988 9.677	38 26.419 5.076 7.211	12 10.879 0.116 2.277	2 2.886 0.272 0.380	117
	26-35	14 18.361 1.036 2.657	57 59.112 0.075 10.816	32 26.645 1.076 6.072	14 10.972 0.836 2.657	1 2.911 1.254 0.190	118
	36-50	20 24.584 0.855 3.795	83 79.150 0.187 15.750	35 35.677 0.013 6.641	15 14.691 0.007 2.846	5 3.898 0.312 0.949	158
	Over 50	34 20.850 8.293 6.452	73 67.127 0.514 13.852	14 30.258 8.736 2.657	8 12.459 1.596 1.518	5 3.306 0.869 0.949	134
	Total	82	264	119	49	13	527

Statistic	DF	Value	Prob
Chi-Square	12	33.082	0.0009
Likelihood Ratio Chi-Square	12	34.0111	0.0007
Mantel-Haenszel Chi-Square	1	10.0233	0.0015
Phi Coefficient		0.2505	
Contingency Coefficient		0.2430	
Cramer's V		0.1447	
Effective Sample Size		527	
Frequency Missing		6	

Table B-13: Chi-square Analysis and Statistics for Question 2 (Driver's Age) and Question 8.1 (Centerline rumble strips installed on the same section of road as shoulder rumble strips make me feel more confident of where I am on the road than centerline rumble strips or shoulder rumble strips alone.)

Frequency Expected Cell Chi-square Percent		Question 8.1 Strongly Agree	Agree	No Opinion	Disagree	Strongly Disagree	Total
Question 2	18-25	11	55	34	15	0	115
		14.127	59.155	26.488	12.140	3.090	
		0.692	0.292	2.131	0.674	3.090	
		2.111	10.557	6.526	2.879	0.000	
	26-35	13	58	30	14	3	118
		14.495	60.699	27.179	12.457	3.171	
		0.154	0.120	0.293	0.191	0.009	
		2.495	11.132	5.758	2.687	0.576	
	36-50	12	82	38	19	6	157
		19.286	80.760	36.161	16.574	4.219	
		2.753	0.019	0.094	0.355	0.752	
		2.303	15.739	7.294	3.647	1.152	
	Over 50	28	73	18	7	5	131
		16.092	67.386	30.173	13.829	3.520	
		8.812	0.468	4.911	3.372	0.622	
		5.374	14.012	3.455	1.344	0.960	
	Total	64	268	120	55	14	521

Statistic	DF	Value	Prob
Chi-Square	12	29.8031	0.0030
Likelihood Ratio Chi-Square	12	32.9470	0.0010
Mantel-Haenszel Chi-Square	1	5.5587	0.0184
Phi Coefficient		0.2392	
Contingency Coefficient		0.2326	
Cramer's V		0.1381	
Effective Sample Size		521	
Frequency Missing		12	

Table B-14: Chi-square Analysis and Statistics of Question 7 (If you fell asleep and your car drifted onto the centerline rumble strips, would you have enough time to react, avoid entering the other lane and safely return your vehicle to your own lane?) and Question 9 (Do centerline rumble strips significantly reduce head-on collisions caused by drivers crossing the centerline?)

Frequency Expected Cell Chi-square Percent		Question 9 Yes	Probably So	No Opinion	Probably Not	No	Total
Question 7	Yes	38 14.532 37.897 7.224	31 35.133 0.486 5.894	13 27.308 7.497 2.471	2 4.471 1.366 0.380	0 2.555 2.555 0.000	84
	Probably So	35 35.466 0.006 6.654	110 85.741 6.863 20.913	50 66.644 4.157 9.506	7 10.913 1.403 1.331	3 6.236 1.679 0.570	205
	No Opinion	13 30.103 9.717 2.471	65 72.776 0.831 12.357	87 56.567 16.374 16.540	7 9.262 0.553 1.331	2 5.293 2.049 0.380	174
	Probably Not	2 6.401 3.026 0.380	12 15.475 0.780 2.281	11 12.029 0.088 2.091	9 1.970 25.095 1.711	3 1.125 3.122 0.570	37
	No	3 4.498 0.499 0.570	2 10.875 7.242 0.380	10 8.452 0.283 1.901	3 1.384 1.887 0.570	8 0.791 65.714 1.521	26
	Total	91	220	171	28	16	526

Statistic	DF	Value	Prob
Chi-Square	16	201.1686	<.0001
Likelihood Ratio Chi-Square	16	144.2262	<.0001
Mantel-Haenszel Chi-Square	1	99.6424	<.0001
Phi Coefficient		0.6184	
Contingency Coefficient		0.5260	
Cramer's V		0.3092	
Effective Sample Size		526	
Frequency Missing		7	
WARNING: 28% of the cells have expected counts of less than 5. Chi-Square may not be a valid test			

Table B-15: Chi-square Analysis and Statistics of Question 7 (If you fell asleep and your car drifted onto the centerline rumble strips, would you have enough time to react, avoid entering the other lane and safely return your vehicle to your own lane?) and Question 9.1 (Would centerline rumble strips with a paved median be preferred over a single centerline rumble strips to improve safety?)

Frequency Expected Cell Chi-square Percent		Question 9.1 Strongly Agree	Agree	No Opinion	Disagree	Strongly Disagree	Total
Question 7	Strongly Agree	29 17.957 6.792 5.731	16 27.543 4.838 3.162	20 23.891 0.634 3.953	3 3.804 0.170 0.593	9 3.804 7.096 1.779	77
	Agree	47 46.640 0.003 9.289	79 71.542 0.778 15.613	56 62.055 0.591 11.067	11 9.881 0.127 2.174	7 9.881 0.840 1.383	200
	No Opinion	29 39.644 2.858 5.731	62 60.810 0.023 12.253	65 52.747 2.846 12.846	9 8.399 0.043 1.779	5 8.399 1.376 0.988	170
	Disagree	7 8.395 0.232 1.383	20 12.877 3.939 3.953	7 11.170 1.557 1.383	1 1.779 0.341 0.198	1 1.779 0.341 0.198	36
	Strongly Disagree	6 5.364 0.076 1.186	4 8.227 2.172 0.791	9 7.136 0.487 1.779	1 1.136 0.016 0.198	3 1.136 3.056 0.593	23
Total		118	181	157	25	25	506

Statistic	DF	Value	Prob
Chi-Square	16	41.2304	0.0005
Likelihood Ratio Chi-Square	16	38.8283	0.0012
Mantel-Haenszel Chi-Square	1	0.8441	0.3582
Phi Coefficient		0.2855	
Contingency Coefficient		0.2745	
Cramer's V		0.1427	
Effective Sample Size		506	
Frequency Missing		27	
WARNING: 24% of the cells have expected counts of less than 5. Chi-Square may not be a valid test			

Table B-16: Chi-square Analysis and Statistics for Question 3F (What type of vehicle do you regularly drive on highways? Heavy Truck) and Question 10 (Assuming poor road visibility conditions, would the presence of centerline rumble strips help drivers stay in their lanes?)

Frequency Expected Cell Chi-square Percent		Question 10 Strongly Agree	Agree	No Opinion	Disagree	Strongly Disagree	Total
Question 3F	Non Heavy Truck	218 226.023 0.285 41.055	192 186.633 0.154 36.158	63 60.960 0.068 11.864	16 15.006 0.066 3.013	9 9.379 0.015 1.695	498
	Heavy Truck	23 14.977 4.297 4.331	7 12.367 2.329 1.318	2 4.040 1.030 0.377	0 0.994 0.994 0.000	1 0.621 0.231 0.188	33
	Total	241	199	65	16	10	531

Statistic	DF	Value	Prob
Chi-Square	4	9.4698	0.0504
Likelihood Ratio Chi-Square	4	10.4918	0.0329
Mantel-Haenszel Chi-Square	1	4.6847	0.3040
Phi Coefficient		0.1335	
Contingency Coefficient		0.1324	
Cramer's V		0.1335	
Effective Sample Size		531	
Frequency Missing		2	

Table B-17: Chi-square Analysis and Statistics for Question 1 (Driver's Gender) and Question 14 (Should the State of Utah install more centerline rumble strips on rural, undivided highways?)

Frequency Expected Cell Chi-square Percent		Question 1 Male	 Female	Total
Question 14	Yes	237 244.359 0.222 51.860	159 151.641 0.357 34.792	396
	No	45 37.641 1.439 9.847	16 23.359 2.318 3.501	61
	Total	282	175	457

Statistic	DF	Value	Prob
Chi-Square	1	4.3357	0.0373
Likelihood Ratio Chi-Square	1	4.5378	0.0332
Continuity Adj. Chi-Square	1	3.7665	0.0523
Mantel-Haenszel Chi-Square	1	4.3262	0.0375
Phi Coefficient		-0.0974	
Contingency Coefficient		0.0969	
Cramer's V		-0.0974	
Effective Sample Size		457	
Frequency Missing		76	

WARNING: 14% of the data are missing

Fisher's Exact Test

Cell (1,1) Frequency (F)	237
Left-Sided Pr <= F	0.0244
Right-Sided Pr >= F	0.9884
Table Probability (P)	0.0127
Two-Sided Probability Pr <= P	0.0470

Table B-18: Chi-square Analysis and Statistics for Question 2 (Driver's Age) and Question 14 (Should the State of Utah install more centerline rumble strips on rural, undivided highways?)

Frequency Expected Cell Chi-square Percent		Question 2 18-25	 26-35	 36-50	 Over 50	 Total
Question 14	Yes	94 93.464 0.003 18.876	93 95.211 0.051 18.675	125 132.771 0.455 25.100	123 113.554 0.786 24.699	435
	No	13 13.536 0.021 2.610	16 13.789 0.354 3.213	27 19.229 3.141 5.422	7 16.446 5.425 1.406	63
	Total	107	109	152	130	498

Statistic	DF	Value	Prob
Chi-Square	3	10.2365	0.0167
Likelihood Ratio Chi-Square	3	11.3620	0.0099
Mantel-Haenszel Chi-Square	1	1.7085	0.1912
Phi Coefficient		0.1434	
Contingency Coefficient		0.1419	
Cramer's V		0.1434	
Effective Sample Size		498	
Frequency Missing		35	

Table B-19: Chi-square Analysis and Statistics for Question 6.1 (Do you think the sound, vibration and feeling of the centerline rumble strips is easily distinguishable from the sound, vibration and feeling of shoulder rumble strips?) and Question 14 (Should the State of Utah install more centerline rumble strips on rural, undivided highways?)

Frequency Expected Cell Chi-square Percent		Question 6.1 Strongly Agree	Agree	No Opinion	Disagree	Strongly Disagree	Total
Question 14	Yes	90 80.640 1.087 18.219	139 134.984 0.119 28.138	124 127.095 0.075 25.101	58 65.739 0.911 11.741	22 24.543 0.263 4.453	433
	No	2 11.360 7.712 0.405	15 19.016 0.848 3.036	21 17.905 0.535 4.251	17 9.261 6.467 3.441	6 3.457 1.870 1.215	61
	Total	92	154	145	75	28	494

Statistic	DF	Value	Prob
Chi-Square	3	19.8880	0.0005
Likelihood Ratio Chi-Square	3	22.3606	0.0002
Mantel-Haenszel Chi-Square	1	18.7381	<.0001
Phi Coefficient		0.2006	
Contingency Coefficient		0.1967	
Cramer's V		0.2006	
Effective Sample Size		494	
Frequency Missing		39	

Table B-20: Chi-square Analysis and Statistics for Question 6.3 (When driving consciously and alertly, how would you react if you drifted onto the centerline rumble strips?) and Question 14 (Should the State of Utah install more centerline rumble strips on rural, undivided highways?)

Frequency Expected Cell Chi-square Percent		Question 6.3 Positive	No Opinion	Negative	Total
Question 14	Yes	305	107	22	434
		273.227	116.846	43.927	
		3.695	0.830	10.945	
		61.741	21.660	4.453	
	No	6	26	28	60
		37.773	16.154	6.073	
		26.726	6.001	79.172	
		1.215	5.263	5.668	
	Total	311	133	50	494

Statistic	DF	Value	Prob
Chi-Square	2	127.3693	<.0001
Likelihood Ratio Chi-Square	2	106.1017	<.0001
Mantel-Haenszel Chi-Square	1	120.8877	<.0001
Phi Coefficient		0.5078	
Contingency Coefficient		0.4527	
Cramer's V		0.5078	
Effective Sample Size		494	
Frequency Missing		39	

Table B-21: Chi-square Analysis and Statistics for Question 6.4 (If you fell asleep while driving, how would you react if you drifted onto the centerline rumble strips?) and Question 14 (Should the State of Utah install more centerline rumble strips on rural, undivided highways?)

Frequency Expected Cell Chi-square Percent		Question 6.4 Positive	 No Opinion	 Negative	 Total
Question 14	Yes	386 367.500 0.931 77.823	33 38.500 0.786 6.653	15 28.000 6.036 3.024	434
	No	34 52.500 6.519 6.855	11 5.500 5.500 2.218	17 4.000 42.250 3.427	62
	Total	420	44	32	496

Statistic	DF	Value	Prob
Chi-Square	2	62.0218	<.0001
Likelihood Ratio Chi-Square	2	43.9192	<.0001
Mantel-Haenszel Chi-Square	1	60.9744	<.0001
Phi Coefficient		0.3536	
Contingency Coefficient		0.3334	
Cramer's V		0.3536	
Effective Sample Size		496	
Frequency Missing		37	

Table B-22: Chi-square Analysis and Statistics for Question 6.5 (Do centerline rumble strips cause drivers to steer dangerously to return their vehicles to their lane?) and Question 14 (Should the State of Utah install more centerline rumble strips on rural, undivided highways?)

Frequency Expected Cell Chi-square Percent		Question 6.5 Strongly Agree	Agree	No Opinion	Disagree	Strongly Disagree	Total
Question 14	Yes	25	52	132	127	101	437
		39.330	57.684	124.982	122.360	92.644	
		5.221	0.560	0.394	0.176	0.754	
		5.000	10.400	26.400	25.400	20.200	
	No	20	14	11	13	5	63
		5.670	8.316	18.018	17.640	13.356	
		36.217	3.885	2.734	1.220	5.228	
		4.000	2.800	2.200	2.600	1.000	
	Total	45	66	143	140	106	500

Statistic	DF	Value	Prob
Chi-Square	2	56.3885	<.0001
Likelihood Ratio Chi-Square	2	44.2653	<.0001
Mantel-Haenszel Chi-Square	1	38.3436	<.0001
Phi Coefficient		0.3358	
Contingency Coefficient		0.3184	
Cramer's V		0.3358	
Effective Sample Size		500	
Frequency Missing		33	

Table B-23: Chi-square Analysis and Statistics for Question 7 (If you fell asleep and your car drifted onto the centerline rumble strips, would you have enough time to react, avoid entering the other lane and safely return your vehicle to your own lane?) and Question 14 (Should the State of Utah install more centerline rumble strips on rural, undivided highways?)

Frequency Expected Cell Chi-square Percent		Question 7					
		Strongly Agree	Agree	No Opinion	Disagree	Strongly Disagree	Total
Question 14	Yes	72	180	145	22	14	433
		69.105	170.576	142.584	28.867	21.869	433.000
		0.121	0.521	0.041	1.633	2.831	5.148
		14.545	36.364	29.293	4.444	2.828	
	No	7	15	18	11	11	62
		9.895	24.424	20.416	4.133	3.131	62
		0.847	3.636	0.286	11.408	19.773	35.950
		1.414	3.030	3.636	2.222	2.222	
	Total	79	195	163	33	25	495

Statistic	DF	Value	Prob
Chi-Square	4	41.0977	<.0001
Likelihood Ratio Chi-Square	4	30.8719	<.0001
Mantel-Haenszel Chi-Square	1	26.2262	<.0001
Phi Coefficient		0.2991	
Contingency Coefficient		0.2769	
Cramer's V		0.2881	
Effective Sample Size		495	
Frequency Missing		38	

Table B-24: Chi- square Analysis and Statistics for Question 8 (The sight, sound or vibration of centerline rumble strips make me feel confodent of where I am and other drivers are on the road.) and Question 14 (Should the State of Utah install more centerline rumble strips on rural, undivided highways?)

Frequency Expected Cell Chi-square Percent		Question 8					
		Strongly Agree	Agree	No Opinion	Disagree	Strongly Disagree	Total
Question 14	Yes	80	241	84	25	7	437
		71.078	219.378	94.771	40.365	11.408	
		1.120	2.131	1.224	5.849	1.703	
		16.064	48.394	16.867	5.020	1.406	
	No	1	9	24	21	6	61
		9.922	30.622	13.229	5.635	1.592	
		8.022	15.268	8.770	41.902	12.200	
		0.201	1.807	4.819	4.217	1.205	
	Total	81	250	108	46	13	498

Statistic	DF	Value	Prob
Chi-Square	4	98.1892	<.0001
Likelihood Ratio Chi-Square	4	86.3020	<.0001
Mantel-Haenszel Chi-Square	1	85.5065	<.0001
Phi Coefficient		0.4440	
Contingency Coefficient		0.4058	
Cramer's V		0.4440	
Effective Sample Size		498	
Frequency Missing		35	

Table B-25: Chi-square Analysis and Statistics for Question 8.1 (Centerline rumble strips installed on the same section of road as shoulder rumble strips make me feel more confident of where I am on the road than centerline rumble strips or shoulder rumble strips alone.) and Question 14 (Should the State of Utah install more centerline rumble strips on rural, undivided highways?)

Frequency Expected Cell Chi-square Percent		Question 8.1 Strongly Agree	Agree	No Opinion	Disagree	Strongly Disagree	Total
Question 14	Yes	63 55.093 1.135 12.753	242 222.996 1.620 48.988	92 96.194 0.183 18.623	31 45.474 4.607 6.275	4 12.243 5.550 0.810	432
	No	0 7.907 7.907 0.000	13 32.004 11.285 2.632	18 13.806 1.274 3.644	21 6.526 32.099 4.251	10 1.757 38.670 2.024	62
	Total	63	255	110	52	14	494

Statistic	DF	Value	Prob
Chi-Square	4	104.3280	<.0001
Likelihood Ratio Chi-Square	4	85.5639	<.0001
Mantel-Haenszel Chi-Square	1	91.1533	<.0001
Phi Coefficient		0.4596	
Contingency Coefficient		0.4176	
Cramer's V		0.4596	
Effective Sample Size		494	
Frequency Missing		39	

Table B-26: Chi-square Analysis and Statistics for Question 9 (Do centerline rumble strips significantly reduce head-on collisions caused by drivers crossing the centerline?) and Question 14 (Should the State of Utah install more centerline rumble strips on rural, undivided highways?)

Frequency Expected Cell Chi-square Percent		Question 9					
		Strongly Agree	Agree	No Opinion	Disagree	Strongly Disagree	Total
Question 14	Yes	86 76.912 1.074	200 189.658 0.564	130 134.596 0.157	16 22.724 1.990	5 13.110 5.017	437
	No	2 11.088 7.449	17 27.342 3.912	24 19.404 1.089	10 3.276 13.801	10 1.890 34.800	63
	Total	88	217	154	26	15	500

Statistic	DF	Value	Prob
Chi-Square	4	69.8515	<.0001
Likelihood Ratio Chi-Square	4	53.3835	<.0001
Mantel-Haenszel Chi-Square	1	56.0942	<.0001
Phi Coefficient		0.3738	
Contingency Coefficient		0.3501	
Cramer's V		0.3738	
Effective Sample Size		500	
Frequency Missing		33	

Table B-27: Chi-square Analysis and Statistics for Question 9.1 (Would centerline rumble strips with a paved median be preferred over a single centerline rumble strips to improve safety?) and Question 14 (Should the State of Utah install more centerline rumble strips on rural, undivided highways?)

Frequency Expected Cell Chi-square Percent		Question 9.1 Strongly Agree	Agree	No Opinion	Disagree	Strongly Disagree	Total
Question 14	Yes	105	152	132	20	16	425
		99.431	153.106	129.348	20.238	22.878	
		0.312	0.008	0.054	0.003	2.068	
		21.739	31.470	27.329	4.141	3.313	
	No	8	22	15	3	10	58
		13.569	20.894	17.652	2.762	3.122	
		2.286	0.059	0.398	0.021	15.151	
		1.656	4.555	3.106	0.621	2.070	
	Total	113	174	147	23	26	483

Statistic	DF	Value	Prob
Chi-Square	4	20.3595	0.0004
Likelihood Ratio Chi-Square	4	15.3921	0.0040
Mantel-Haenszel Chi-Square	1	10.2041	0.0014
Phi Coefficient		0.2053	
Contingency Coefficient		0.2011	
Cramer's V		0.2053	
Effective Sample Size		483	
Frequency Missing		50	

Table B-28: Chi-square Analysis and Statistics for Question 10 (Assuming poor road visibility conditions, would the presence of centerline rumble strips help drivers stay in their lanes?) and Question 14 (Should the State of Utah install more centerline rumble strips on rural, undivided highways?)

Frequency Expected Cell Chi-square Percent		Question 10 Strongly Agree	Agree	No Opinion	Disagree	Strongly Disagree	Total
Question 14	Yes	223 201.836 2.219	165 162.517 0.038	42 49.804 1.223	6 13.980 4.555	0 7.864 7.864	436
	No	8 29.164 15.359	21 23.483 0.263	15 7.196 8.462	10 2.020 31.524	9 1.136 54.422	63
	Total	231	186	57	16	9	499

Statistic	DF	Value	Prob
Chi-Square	4	125.9281	<.0001
Likelihood Ratio Chi-Square	4	90.8966	<.0001
Mantel-Haenszel Chi-Square	1	104.4884	<.0001
Phi Coefficient		0.5024	
Contingency Coefficient		0.4489	
Cramer's V		0.5024	
Effective Sample Size		499	
Frequency Missing		34	

Table B-29: Chi-square Analysis and Statistics for Question 11 (Do centerline/shoulder rumble strips cause a significant loss of vehicle control when contacted?) and Question 14 (Should the State of Utah install more centerline rumble strips on rural, undivided highways?)

Frequency Expected Cell Chi-square Percent		Question 11 Strongly Agree	Agree	No Opinion	Disagree	Strongly Disagree	Total
Question 14	**Yes**	14 27.070 6.311 2.817	28 28.817 0.023 5.634	70 74.225 0.241 14.085	102 103.915 0.035 20.523	220 199.972 2.006 44.266	434
	No	17 3.930 43.474 3.421	5 4.183 0.160 1.006	15 10.775 1.657 3.018	17 15.085 0.243 3.421	9 29.028 13.819 1.811	63
	Total	31	33	85	119	229	497

Statistic	**DF**	**Value**	**Prob**
Chi-Square	4	67.9684	<.0001
Likelihood Ratio Chi-Square	4	54.4188	<.0001
Mantel-Haenszel Chi-Square	1	52.7332	<.0001
Phi Coefficient		0.3698	
Contingency Coefficient		0.3468	
Cramer's V		0.3698	
Effective Sample Size		497	
Frequency Missing		36	

Table B-30: Chi-square Analysis and Statistics of Question 13 (Are the double yellow lines more visible when painted over the centerline rumble strips than on flat pavement?) and Question 14 (Should the State of Utah install more centerline rumble strips on rural, undivided highways?)

Frequency Expected Cell Chi-square Percent		Question 13 Strongly Agree	Agree	No Opinion	Disagree	Strongly Disagree	Total
Question 14	Yes	32	140	216	45	5	438
		31.663	131.048	211.084	52.771	11.434	
		0.004	0.611	0.114	1.144	3.620	
		6.426	28.112	43.373	9.036	1.004	
	No	4	9	24	15	8	60
		4.337	17.952	28.916	7.229	1.566	
		0.026	4.464	0.836	8.354	26.428	
		0.803	1.807	4.819	3.012	1.606	
	Total	36	149	240	60	13	498

Statistic	DF	Value	Prob
Chi-Square	4	45.6017	<.0001
Likelihood Ratio Chi-Square	4	32.4873	<.0001
Mantel-Haenszel Chi-Square	1	23.4164	<.0001
Phi Coefficient		0.3026	
Contingency Coefficient		0.2896	
Cramer's V		0.3026	
Effective Sample Size		498	
Frequency Missing		35	

APPENDIX C: EXAMPLE OF STATE OF THE PRACTICE SURVEY

November 11, 2004

Robert Hull *Phone Number* (801) 965-4273
Engineer for Traffic and Safety *Fax Number* (801) 965-4736
Utah Department of Transportation
P.O. Box 143200
Salt Lake City, UT 84114-3200 *E-mail Address:* rhull@utah.gov

Brigham Young University (BYU) is conducting on behalf of the Utah Department of Transportation (UDOT) an evaluation of centerline rumble strips on rural, two-way, undivided highways. We have prepared a technical information survey that is being distributed to each of the 50 state departments of transportation. We hope that you will assist us by completing the survey.

We recognize the demands of your position and appreciate the efforts that will be made to complete the survey. In recognition of your busy schedule, please use as many co-employees as possible to aid in the quick and efficient completion of this survey. Our goal is to have them completed by December 31, 2004.We have given you two options to complete the survey: this copy and an electronic version of the survey. Enclosed with this letter is a hard copy of the survey. The electronic version of the survey will be or has been e-mailed from Sam Richards to your e-mail address listed at http://transportation1.org/scote/doc/Roster.pdf

Completed hard copy surveys should be returned to:

Dr. Mitsuru Saito, Ph.D., P.E.
Brigham Young University
Department of Civil and Environmental Engineering
368 Clyde Building
Provo, Utah 84602

This information will supplement the establishment of a guidelines manual for centerline rumble strips in Utah. This will allow the State of Utah to make an educated decision on improving the safety and effectiveness of our highway systems.

Thank you for participating in this research project. We are looking forward to using this information to make our highways safer!

Sincerely,

Mitsuru Saito, Ph.D., P.E.

Sam Richards, Research Assistant, Brigham Young University
Phone: 801-422-2685 Email: sjnrichards@msn.com

STATE OF THE PRACTICE: CENTERLINE RUMBLE STRIPS

INTRODUCTION

Brigham Young University (BYU) is conducting on behalf of the Utah Department of Transportation (UDOT) an evaluation of the implementation of centerline rumble strips (CRS) on two-way, undivided highways. In conjunction with an extensive literature search, UDOT is hoping to gather the most current data on centerline rumble strips. This information will supplement the establishment of guidelines for centerline rumble strips in Utah. This will allow the State of Utah to make an educated decision on improving the safety and effectiveness of our highway systems.

INSTRUCTIONS

If the state has any of the following:

1. Manual of Guidelines for Centerline Rumble Strips
2. Documentation of Centerline Rumble Strip Research

Please send a copy of the document and payment invoice to be reimbursed for document copies to:

Dr. Mitsuru Saito
Brigham Young University
Department of Civil and Environmental Engineering
368 Clyde Building
Provo, Utah 84602

Or send an Internet URL (address) of the document(s) to: sjnrichards@msn.com

There are two versions of this survey that are being distributed to each of the 50 state departments of transportation. One version is an electronic version and the other is this hardcopy. The electronic version will have been sent out approximately one week after the hard copy has been mailed out. Hence, there are two methods in which the survey may be completed. The electronic method is preferred. If you choose to fill out the survey electronically, save the survey under an appropriate name in an appropriate folder. The survey has been created in such a way that option buttons, scroll boxes and text boxes are attached to each question. Large textboxes will scroll to allow you to input more information. Send the completed survey as an attached file to the email address above.

If you choose to fill out the hardcopy, appropriate answers have been provided for certain questions. Where answers are provided, please circle the most appropriate answer. Other questions require a freestyle type of response. Hopefully, adequate space has been allotted. If not, please attach properly labeled answers to the survey. When you have completed the survey, mail it to the address above.

If appropriate data is not available, leave the response empty. Please be as complete as possible!

If you have any questions, contact Sam Richards by email at: sjnrichards@msn.com

Thank you for taking the time to complete this questionnaire!

QUESTIONNAIRE

1 Information

a. What state is this response from?

b. If the contact person's information has changed, please include the new contact information:

c. Survey completion date. Data reported in this survey will be considered current as of the completion date: (Month, Day, 2004)

2 Status of Centerline Rumble Strips

a. Is the state currently using centerline rumble strips?

Yes **No**

i If you answered "No" to question 'a', then, has the state decided against using centerline rumble strips?

Yes **No**

☆ If you answered "No" to Question 'i', you may stop the survey at this point

ii If you answered "Yes" to question 'i', then, briefly explain why the state has decided against using centerline rumble strips? (Please describe the centerline rumble strips used by completing the survey)

b. What is the mileage of centerline rumble strips used in the state?

i Multi-lane, rural, undivided two-way highways? (Circle desired units)

Miles

Kilometers

ii Two-lane, rural, undivided two-way highways? (Circle desired units)

Miles

Kilometers

3 Dimensions and Types of Centerline Rumble Strips

A layout is the dimensional pattern an agency uses when installing centerline rumble strips. If the state uses multiple layouts or patterns for centerline rumble strips, specify the dimensions in the layout columns below from more to less frequently used layouts. (i.e. Layout #1 is the most frequently used pattern in the state) These columns continue throughout the remainder of the survey.

a. Using Figure 1 as a reference, define the centerline rumble strip dimensions used by the state by layout. In each column there are two textboxes for entering values. In the first box enter the dimension (Dim.) and in the second box enter the tolerances (Tol.), if known.

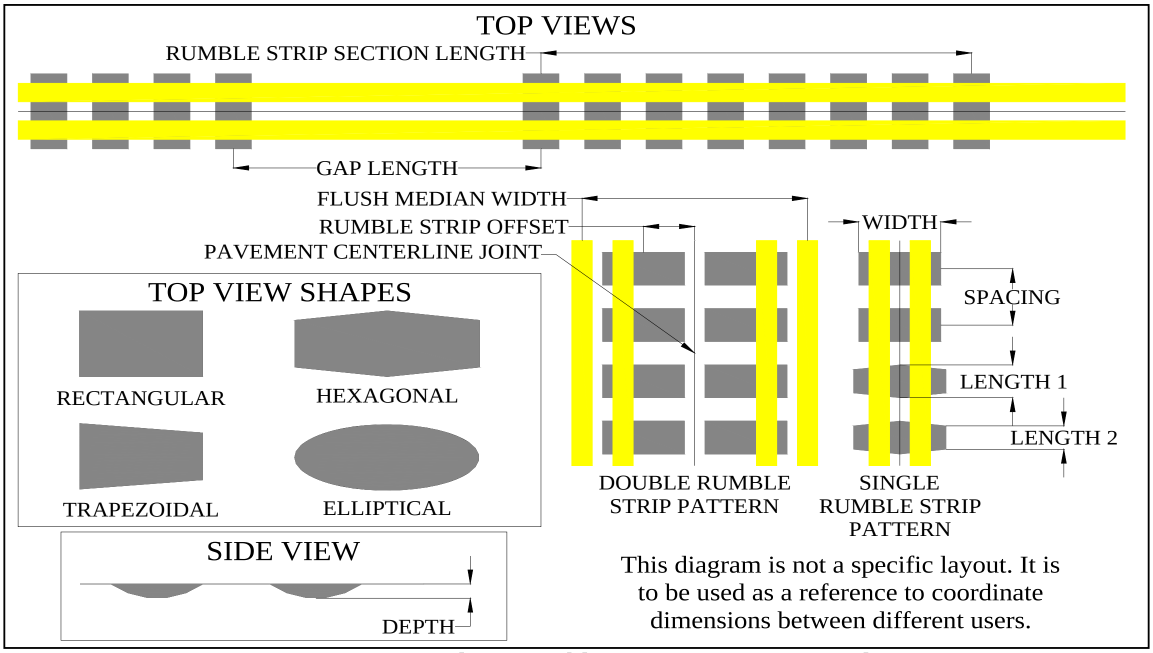

Figure 1. Centerline Rumble Strip Dimension Guide

	Layout #1	Layout #2	Layout #3	Layout #4
i Shape (Circle the appropriate shape from each layout list. Shape may be the same for each layout)	**Rectangular** **Trapezoidal** **Hexagonal** **Elliptical** **Other**	**Rectangular** **Trapezoidal** **Hexagonal** **Elliptical** **Other**	**Rectangular** **Trapezoidal** **Hexagonal** **Elliptical** **Other**	**Rectangular** **Trapezoidal** **Hexagonal** **Elliptical** **Other**

Rectangular shapes use Length 1 and Depth 1. Other shapes use Length 1, Length 2, Depth 1, and Depth 2. Depth 1 is the groove depth at Length 1, and Depth 2 is the groove depth at Length 2.

ii Units of Measurement for questions 'ii' to 'vii' and 'ix': (Circle desired units)

	Layout #1			Layout #2			Layout #3			Layout #4		
	Centimeters **Inches** **Feet** **Meters**			**Centimeters** **Inches** **Feet** **Meters**			**Centimeters** **Inches** **Feet** **Meters**			**Centimeters** **Inches** **Feet** **Meters**		
	Dim.		Tol.	Dim.		Tol.	Dim.		Tol.	Dim.		Tol.
ii Length 1:		±			±			±			±	
Length 2:		±			±			±			±	
iii Width:		±			±			±			±	
iv Depth 1:		±			±			±			±	
Depth 2:		±			±			±			±	

	Layout #1	Layout #2	Layout #3	Layout #4
v Spacing:	±	±	±	±
vi Rumble Strip Offset:	±	±	±	±
vii Single or Double Rumble Strip Pattern: (Circle desired pattern)	**Single** **Double**	**Single** **Double**	**Single** **Double**	**Single** **Double**
viii Flush Median Width:	±	±	±	±
ix Continuous or Gapped: (Circle desired pattern)	**Continuous** **Gapped** **Both/Either**	**Continuous** **Gapped** **Both/Either**	**Continuous** **Gapped** **Both/Either**	**Continuous** **Gapped** **Both/Either**
x Units of Measurement for questions 'xi' and 'xii' if 'ix' is Gapped or Both/Either: (Circle desired units)	**Centimeters** **Inches** **Feet** **Meters**	**Centimeters** **Inches** **Feet** **Meters**	**Centimeters** **Inches** **Feet** **Meters**	**Centimeters** **Inches** **Feet** **Meters**
	Dim. Tol.	Dim. Tol.	Dim. Tol.	Dim. Tol.
xi Gap Length:	±	±	±	±
xii Rumble Strip Section Length:	±	±	±	±
xiii Other dimensions not considered:				
b. Installation Method (Layout Method) Used. Describe "other" method in space provided below. Use Figures 2 to 5 below.				

Figure 2. Raised Pavement Markers

Figure 3. Milled-in Rumble Strips

Figure 4. Rolled-in Rumble Strips

Figure 5. Formed-in Rumble Strips

4 Highway Characteristics Influencing Centerline Rumble Strip Implementation

In answering the following questions, If the layout (same as Question 3) is to be used, what are the minimum guidelines needed to allow the addition of centerline rumble strips to the existing road.

a. Highway Dimensions
Use Figure 6 as a reference to answer questions 4.a.i to 4.a.viii

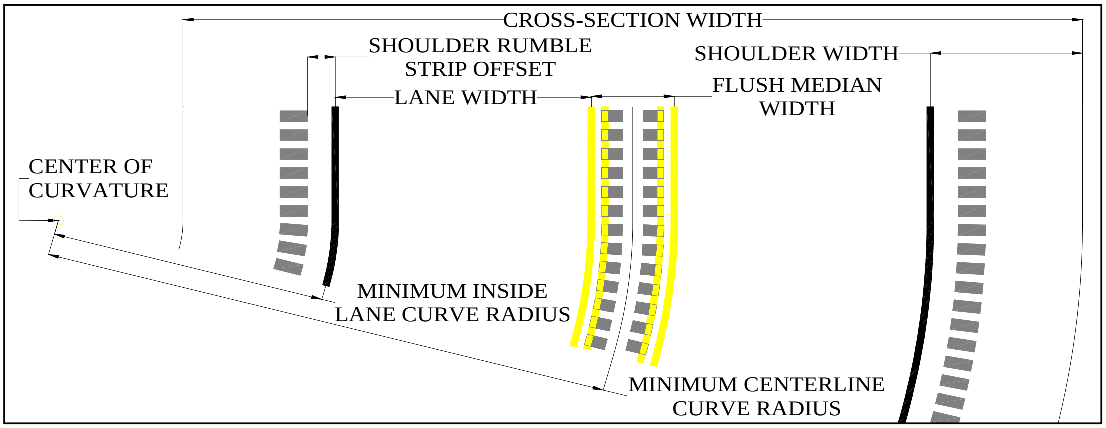

Figure 6. Highway Plan

	Layout #1	Layout #2	Layout #3	Layout #4
i Units of Measurement for questions 4.a.ii to 4.a.vi: (Circle desired units)	**Feet** **Meters**	**Feet** **Meters**	**Feet** **Meters**	**Feet** **Meters**
	Dim. Tol.	Dim. Tol.	Dim. Tol.	Dim. Tol.
ii Minimum Lane Width:	±	±	±	±
iii Minimum Shoulder Width:	±	±	±	±
iv Minimum Cross-Section Width:	±	±	±	±
v Minimum Centerline Curve Radius:	±	±	±	±
vi Minimum Inside Lane Curve Radius:	±	±	±	±
vii Pattern of Installed Shoulder Rumble Strips: (Circle desired pattern)	**Continuous** **Gapped** **Both/Either**	**Continuous** **Gapped** **Both/Either**	**Continuous** **Gapped** **Both/Either**	**Continuous** **Gapped** **Both/Either**
viii Minimum Shoulder Rumble Strip Offset from the outside edge of the outside lane:	±	±	±	±
Question 4.1.8 Units: (Circle desired units)	**Centimeters** **Inches** **Feet** **Meters**	**Centimeters** **Inches** **Feet** **Meters**	**Centimeters** **Inches** **Feet** **Meters**	**Centimeters** **Inches** **Feet** **Meters**
ix Maximum Percent Grade: (Upslope = Downslope)	%	%	%	%

b. Highway Operations	Layout #1	Layout #2	Layout #3	Layout #4
i Minimum Speed Limit for Installation (Speed = Spd., Circle desired units):				
	Spd. Units	Spd. Units	Spd. Units	Spd. Units
	Mph	**Mph**	**Mph**	**Mph**
	Km/h	**Km/h**	**Km/h**	**Km/h**
ii Installed in Two-Way No-Passing Zones?				
	Yes No	**Yes No**	**Yes No**	**Yes No**
If "Yes", are the centerline rumble strips continuous or gapped?				
	Continuous	**Continuous**	**Continuous**	**Continuous**
	Gapped	**Gapped**	**Gapped**	**Gapped**
iii Installed in One-Way Passing Zones?				
	Yes No	**Yes No**	**Yes No**	**Yes No**
If "Yes", are the centerline rumble strips continuous or gapped?				
	Continuous	**Continuous**	**Continuous**	**Continuous**
	Gapped	**Gapped**	**Gapped**	**Gapped**
iv Installed in Two-Way Passing Zones?				
	Yes No	**Yes No**	**Yes No**	**Yes No**
If "Yes", are the centerline rumble strips continuous or gapped?				
	Continuous	**Continuous**	**Continuous**	**Continuous**
	Gapped	**Gapped**	**Gapped**	**Gapped**
v Number of Lanes (Both directions):				
Minimum:				
Maximum:				
vi Design Traffic Volumes (Both directions):				
Volume Units:				
Minimum:				
Maximum:				

5 Costs Associated with Centerline Rumble Strips

In answering the following questions, assume the same layout patterns as questions 3 and 4. Installation costs include the installation process, labor, and traffic control. Do not include paving or marking costs.

	Layout #1	Layout #2	Layout #3	Layout #4
a. Asphalt	Cost / Unit	Cost / Unit	Cost / Unit	Cost / Unit
i Average Installation Cost:				
ii Lowest Installation Cost:				
b. Portland Cement Concrete	Cost / Unit	Cost / Unit	Cost / Unit	Cost / Unit
i Average Installation Cost:				
ii Lowest Installation Cost:				

c. What techniques has the state used to reduce the cost of installing centerline rumble strips?

d. What types of costs are incurred after the installation of centerline rumble strips? (extra maintenance, pavement marking replacement, early resurfacing, etc.)

e. What techniques are used to reduce after-installation costs of centerline rumble strips?

6 Noise Generation and Control

a. Excess noise created by rumble strips is a primary concern voiced by rural residents. However, it is the audible warning created by rumble strips that makes them effective. What efforts can be made to reduce noise to the surrounding areas while maintaining centerline rumble strip effectiveness?

b. If placement restrictions of centerline rumble strips exist, what is the closest distance that centerline rumble strips may be installed to residencies, businesses loacted beside the highway?

	Layout #1	Layout #2	Layout #3	Layout #4
Units: (Circle desired units)	**Feet** **Meters** **Miles** **Kilometers**	**Feet** **Meters** **Miles** **Kilometers**	**Feet** **Meters** **Miles** **Kilometers**	**Feet** **Meters** **Miles** **Kilometers**
Distance:				

7 Accident Reduction

Provide information acquired by your state agencies only.

a. Head-on crashes per 100 million vehicle miles before installing centerline rumble strips?				
b. Head-on crashes per 100 million vehicle miles after installing centerline rumble strips?				
e. Fatal crashes per 100 million vehicle miles before installing centerline rumble strips?				
f. Fatal crashes per 100 million vehicle miles after installing centerline rumble strips?				
g. Percent of total crossover accidents occuring on straight sections of rural, undivided highways	%	%	%	%
h. Percent of total crossover accidents occuring on straight sections of rural, undivided highways	%	%	%	%

i. What design characteristics of the centerline rumble strip has the greatest effect on reducing head-on collisions? (Shape, placement, median width, etc.)

j. What design characteristics of the centerline rumble strip has the greatest effect on reducing fatalities caused by cross over centerline crashes? (Shape, placement, median width, etc.)

Thank You for completeing the survey! Return the completed survey by mail to the address at the beginning of the survey.

APPENDIX D: STATE OF THE PRACTICE SURVEY DATA

Table D-1: Summary of Contacts

State	Contact	Email	Address	City	Zip	Phone	Fax
Alabama	Timothy Taylor	taylort@dot.state.al.us	1409 Coliseum Boulevard	Montgomery	36130-3050	(334) 242-6275	(334) 242-6378
Alaska	Kurtis Smith	kurt_smith@dot.state.ak.us				(907) 465-6963	
Arizona	Richards S. Weeks		2828 N. Central Ave. Suite 900	Phoenix	85004-1026		
Arkansas	Eric Phillips	eric.phillips@arkansashighways.com				(501) 569-2232	
California	Don Howe	dhowe@dot.ca.gov				(916) 654-2634	
Colorado	Dwayne Wilkinson	dwayne.wilkinson@dot.state.co.us				(303) 512-5134	
Connecticut	John Carey	john.f.carey@po.state.ct.us					
Delaware	Randall Grunden	rgrunden@mail.dot.state.de.us	169 Brickstore Landing Rd.	Smyrna	19977	(320) 659-2025	
Washington D.C,	Douglas Noble	douglas.noble@dc.gov					
Florida	Lap Thong Hoang	lap.hoang@dot.state.fl.us				(850) 410-5413	
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Hawaii	Steven Yoshida	steven.yoshida@hawaii.gov				(808) 692-7682	
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Illinois	Joseph Hill	hilljs@nt.dot.state.il.us					
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Iowa	Timothy Crouch	tim.crouch@dot.iowa.gov	800 Lincoln Way	Ames	50010	(515) 239-1513	(515) 239-1891
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Maryland	Thomas Hicks	thicks@sha.state.md.us				(410) 787-5815	
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New Hampshire	Bill Lambert	wlambert@dot.state.nh.us				(603) 271-2291	

Table D-2: Summary of Contacts Continued

State	Contact	Email	Address	City	Zip	Phone	Fax
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New York	Stan Darwak	sdarwak@dot.state.ny.us					
North Carolina	Brian Mayhew	jklacy@dot.state.nc.us				(919) 715-7818	
North Dakota	Al Covlin	acovlin@state.nd.us					
Ohio	Dave Holstein	dave.holstein@dot.state.oh.us					
Oklahoma	Harold Smart	hsmart@odot.org				(405) 521-2861	
Oregon	Timothy Burks	timothy.w.burks@odot.state.or.us					
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South Dakota	John Adler	john.adler@state.sd.us					
Tennessee	Mike Tugwell	mike.tugwell@state.tn.us				(615) 741-2466	
Texas	Brian A. Stanford		125 E. 11th. Street	Austin	78701		
Utah	Robert Hull	rhull@utah.gov					
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Virginia	Raymond Khoury	raymond.khoury@virginiadot.org					
Washington	Dave Olsen		PO Box 47329	Olympia	98504-7329	(360) 705-7952	
West Virginia	Cindy Cramer	ccramer@dot.state.wv.us				(304) 558-3063	
Wisconsin	Tom Notbohm	thomas.notbohm@dot.state.wi.us	PO Box 7986, Room 501	Madison	53707-7986	(608) 266-0982	
Wyoming	Mike Gostovich	mike.gostovich@dot.state.wy.us					

Table D-3: Descriptive Statistics of UDOT/BYU State of the Practice Survey

	Maximum	Minimum	Mode	Mean	Stdev	Conf (95%)
Length (in)	**8**	**5**	**7**	**6.900**	**0.528**	**0.0074**
Width (in)	24	6	16	14.421	4.451	0.0640
Depth (in)	0.6125	0.315	0.5	0.478	0.063	0.0009
Spacing (in)	24	12	12	15.294	5.336	0.0811
RS Offset (in)	11	0	0	1.750	4.093	0.0741
Number of Rows	2	1	1	1.158	0.375	0.0054
FM Width (in)	72	8	48	37.600	27.070	0.7591
Gap/Continuous	0	0	#N/A			
Gap Length (in)	360	24	24	103.200	144.399	4.0494
RS Section Length (in)	180	12	#N/A	84.000	80.200	2.5145
Minimum Lane Width (ft)	12	10	12	11.163	0.835	0.0185
Minimum Shoulder Width (ft)	6	0	4	3.143	1.864	0.0442
Minimum Cross-Section Width (ft)	30	20	#N/A	24.600	4.336	0.1216
SRS Gap/Continuous	0	0	#N/A			
Minimum SRS Offset (in)	12	0	#N/A	4.600	4.775	0.1339
Minimum Design Speed (mph)	55	50	#N/A	52.500	3.536	0.1568
Install in No Passing Zones	0	0	#N/A			
Install in One-Way Passing Zones	0	0	#N/A			
Install in Two-Way Passing Zones	0	0	#N/A			
Cost ($/ft)	2	0.19	0.39	0.618	0.654	0.0118

Table D-4: CLRS Dimensions Ranked by Longitudinal Length

Length (in)	5	6.5	6.5	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	8
Width (in)	12	12	12	6	12	12	12	12	16	16	16	16	16	16	16	16	24	24	N/A	8
Depth (in)	0.315	0.5	0.5	0.375	0.4375	0.5	0.5	0.6125	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.375	0.4375
Spacing (in)	12	12	12	12	12	12	12	12	12	12	12	24	24	24	N/A	N/A	12	24	N/A	20
RS Offset (in)	N/A	0	0	0	N/A	0	N/A	0	0	0	N/A	0	10	N/A	0	N/A	N/A	0	N/A	11
Number of Rows	N/A	1	1	1	1	1	1	1	1	1	1	1	2	1	2	1	1	1	1	2
FM Width (in)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	48	72	N/A	N/A	12	N/A	48	N/A	N/A	N/A	N/A	8
Gap/Continuous	Cont	Cont	Gap	Cont	Both	Cont	Cont	Cont	Cont	Cont	Cont	Cont	Gap	Cont	Gap	Cont	Cont	Cont	Both	Cont
Gap Length (in)	N/A	N/A	24	N/A	24	N/A	N/A	N/A	N/A	N/A	N/A	N/A	48	N/A	60	N/A	N/A	N/A	360	N/A
RS Section Length (in)	N/A	N/A	N/A	N/A	12	N/A	N/A	N/A	N/A	N/A	N/A	N/A	24	N/A	180	N/A	N/A	N/A	120	N/A
Minimum Lane Width (ft)	12	N/A	N/A	12	10	N/A	N/A	12	N/A	N/A	N/A	10	11	N/A	N/A	N/A	11	N/A	N/A	11.3
Minimum Shoulder Width (ft)	N/A	N/A	N/A	4	2	N/A	N/A	N/A	N/A	N/A	N/A	0	3	N/A	N/A	N/A	4	N/A	6	3
Minimum Cross-Section Width (ft)	N/A	N/A	N/A	N/A	24	N/A	N/A	21	N/A	N/A	N/A	20	28	N/A	N/A	N/A	N/A	N/A	N/A	30
SRS Gap/Continuous	N/A	N/A	N/A	N/A	Cont	N/A	N/A	N/A	N/A	N/A	N/A	No	N/A	N/A	N/A	N/A	Both	N/A	Gap	No
Minimum SRS Offset (in)	N/A	N/A	N/A	1	0	N/A	6	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	12	N/A	4	N/A
Minimum Design Speed (mph)	N/A	N/A	N/A	N/A	50	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	55
Install in No Passing Zones	N/A	N/A	N/A	Cont	Gap	Cont	Cont	Cont	Cont	Cont	N/A	Cont	Gap	N/A	N/A	N/A	Cont	Cont	Cont	Cont
Install in One-Way Passing Zones	N/A	N/A	N/A	Cont	Gap	Cont	No	N/A	No	No	N/A	No	No	N/A	N/A	N/A	Cont	Cont	Cont	Cont
Install in Two-Way Passing Zones	N/A	N/A	N/A	Cont	Gap	Cont	No	N/A	No	No	N/A	No	No	N/A	N/A	N/A	Cont	Cont	Cont	Cont
Cost ($/ft)	N/A	N/A	N/A	0.23	0.37	0.19	N/A	0.24	0.39	0.39	N/A	2	2	N/A	0.3	0.3	0.6	0.4	N/A	N/A

Table D- 5: CLRS Dimensions Ranked by Width (Transverse Length)

Width (in)	6	8	12	12	12	12	12	12	12	16	16	16	16	16	16	16	16	24	24	N/A
Length (in)	7	8	5	6.5	6.5	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
Depth (in)	0.375	0.4375	0.315	0.5	0.5	0.4375	0.5	0.5	0.6125	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.375
Spacing (in)	12	20	12	12	12	12	12	12	12	12	12	12	24	24	24	N/A	N/A	12	24	N/A
RS Offset (in)	0	11	N/A	0	0	N/A	0	N/A	0	0	0	N/A	0	10	N/A	0	N/A	N/A	0	N/A
Number of Rows	1	2	N/A	1	1	1	1	1	1	1	1	1	1	2	1	2	1	1	1	1
FM Width (in)	N/A	8	N/A	N/A	N/A	N/A	N/A	N/A	N/A	48	72	N/A	N/A	12	N/A	48	N/A	N/A	N/A	N/A
Gap/Continuous	Cont	Cont	Cont	Cont	Gap	Both	Cont	Cont	Cont	Cont	Cont	Cont	Cont	Gap	Cont	Gap	Cont	Cont	Cont	Both
Gap Length (in)	N/A	N/A	N/A	N/A	24	24	N/A	N/A	N/A	N/A	N/A	N/A	N/A	48	N/A	60	N/A	N/A	N/A	360
RS Section Length (in)	N/A	N/A	N/A	N/A	N/A	12	N/A	N/A	N/A	N/A	N/A	N/A	N/A	24	N/A	180	N/A	N/A	N/A	120
Minimum Lane Width (ft)	12	11.3	12	N/A	N/A	10	N/A	N/A	12	N/A	N/A	N/A	10	11	N/A	N/A	N/A	11	N/A	N/A
Minimum Shoulder Width (ft)	4	3	N/A	N/A	N/A	2	N/A	N/A	N/A	N/A	N/A	N/A	0	3	N/A	N/A	N/A	4	N/A	6
Minimum Cross-Section Width (ft)	N/A	30	N/A	N/A	N/A	24	N/A	N/A	21	N/A	N/A	N/A	20	28	N/A	N/A	N/A	N/A	N/A	N/A
SRS Gap/Continuous	N/A	No	N/A	N/A	N/A	Cont	N/A	N/A	N/A	N/A	N/A	N/A	No	N/A	N/A	N/A	N/A	Both	N/A	Gap
Minimum SRS Offset (in)	1	N/A	N/A	N/A	N/A	0	N/A	6	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	12	N/A	4
Minimum Design Speed (mph)	N/A	55	N/A	N/A	N/A	50	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Install in No Passing Zones	Cont	Cont	N/A	N/A	N/A	Gap	Cont	Cont	Cont	Cont	Cont	N/A	Cont	Gap	N/A	N/A	N/A	Cont	Cont	Cont
Install in One-Way Passing Zones	Cont	Cont	N/A	N/A	N/A	Gap	Cont	No	N/A	No	No	N/A	No	No	N/A	N/A	N/A	Cont	Cont	Cont
Install in Two-Way Passing Zones	Cont	Cont	N/A	N/A	N/A	Gap	Cont	No	N/A	No	No	N/A	No	No	N/A	N/A	N/A	Cont	Cont	Cont

Table D- 6: CLRS Dimensions Ranked by Depth

Depth (in)	0.315	0.375	0.375	0.4375	0.4375	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.6125
Length (in)	5	7	7	7	8	6.5	6.5	7	7	7	7	7	7	7	7	7	7	7	7	7
Width (in)	12	6	N/A	12	8	12	12	12	12	16	16	16	16	16	16	16	16	24	24	12
Spacing (in)	12	12	N/A	12	20	12	12	12	12	12	12	12	24	24	24	N/A	N/A	12	24	12
RS Offset (in)	N/A	0	N/A	N/A	11	0	0	0	N/A	0	0	N/A	0	10	N/A	0	N/A	N/A	0	0
Number of Rows	N/A	1	1	1	2	1	1	1	1	1	1	1	1	2	1	2	1	1	1	1
FM Width (in)	N/A	N/A	N/A	N/A	8	N/A	N/A	N/A	N/A	48	72	N/A	N/A	12	N/A	48	N/A	N/A	N/A	N/A
Gap/Continuous	Cont	Cont	Both	Both	Cont	Cont	Gap	Cont	Cont	Cont	Cont	Cont	Cont	Gap	Cont	Gap	Cont	Cont	Cont	Cont
Gap Length (in)	N/A	N/A	360	24	N/A	N/A	24	N/A	N/A	N/A	N/A	N/A	N/A	48	N/A	60	N/A	N/A	N/A	N/A
RS Section Length (in)	N/A	N/A	120	12	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	24	N/A	180	N/A	N/A	N/A	N/A
Minimum Lane Width (ft)	12	12	N/A	10	11.3	N/A	N/A	N/A	N/A	N/A	N/A	N/A	10	11	N/A	N/A	N/A	11	N/A	12
Minimum Shoulder Width (ft)	N/A	4	6	2	3	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0	3	N/A	N/A	N/A	4	N/A	N/A
Minimum Cross-Section Width (ft)	N/A	N/A	N/A	24	30	N/A	N/A	N/A	N/A	N/A	N/A	N/A	20	28	N/A	N/A	N/A	N/A	N/A	21
SRS Gap/Continuous	N/A	N/A	Gap	Cont	No	N/A	N/A	N/A	N/A	N/A	N/A	N/A	No	N/A	N/A	N/A	N/A	Both	N/A	N/A
Minimum SRS Offset (in)	N/A	1	4	0	N/A	N/A	N/A	N/A	N/A	6	N/A	N/A	N/A	N/A	N/A	N/A	N/A	12	N/A	N/A
Minimum Design Speed (mph)	N/A	N/A	N/A	50	55	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Install in No Passing Zones	N/A	Cont	Cont	Gap	Cont	N/A	N/A	Cont	Cont	Cont	Cont	N/A	Cont	Gap	N/A	N/A	N/A	Cont	Cont	Cont
Install in One-Way Passing Zones	N/A	Cont	Cont	Gap	Cont	N/A	N/A	Cont	No	No	No	N/A	No	No	N/A	N/A	N/A	Cont	Cont	N/A
Install in Two-Way Passing Zones	N/A	Cont	Cont	Gap	Cont	N/A	N/A	Cont	No	No	No	N/A	No	No	N/A	N/A	N/A	Cont	Cont	N/A

Table D- 7: CLRS Dimensions Ranked by Spacing

Spacing (in)	12	12	12	12	12	12	12	12	12	12	12	12	20	24	24	24	24	N/A	N/A	N/A
Length (in)	5	6.5	6.5	7	7	7	7	7	7	7	7	7	8	7	7	7	7	7	7	7
Width (in)	12	12	12	6	12	12	12	12	16	16	16	24	8	16	16	16	24	16	16	N/A
Depth (in)	0.315	0.5	0.5	0.375	0.4375	0.5	0.5	0.6125	0.5	0.5	0.5	0.5	0.4375	0.5	0.5	0.5	0.5	0.5	0.5	0.375
RS Offset (in)	N/A	0	0	0	N/A	0	N/A	0	0	0	N/A	N/A	11	0	10	N/A	0	0	N/A	N/A
Number of Rows	N/A	1	1	1	1	1	1	1	1	1	1	1	2	1	2	1	1	2	1	1
FM Width (in)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	48	72	N/A	N/A	8	N/A	12	N/A	N/A	48	N/A	N/A
Gap/Continuous	Cont	Cont	Gap	Cont	Both	Cont	Cont	Cont	Cont	Cont	Cont	Cont	Cont	Cont	Gap	Cont	Cont	Gap	Cont	Both
Gap Length (in)	N/A	N/A	24	N/A	24	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	48	N/A	N/A	60	N/A	360
RS Section Length (in)	N/A	N/A	N/A	N/A	12	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	24	N/A	N/A	180	N/A	120
Minimum Lane Width (ft)	12	N/A	N/A	12	10	N/A	N/A	12	N/A	N/A	N/A	11	11.3	10	11	N/A	N/A	N/A	N/A	N/A
Minimum Shoulder Width (ft)	N/A	N/A	N/A	4	2	N/A	N/A	N/A	N/A	N/A	N/A	4	3	0	3	N/A	N/A	N/A	N/A	6
Minimum Cross-Section Width (ft)	N/A	N/A	N/A	N/A	24	N/A	N/A	21	N/A	N/A	N/A	N/A	30	20	28	N/A	N/A	N/A	N/A	N/A
SRS Gap/Continuous	N/A	N/A	N/A	N/A	Cont	N/A	N/A	N/A	N/A	N/A	N/A	Both	No	No	N/A	N/A	N/A	N/A	N/A	Gap
Minimum SRS Offset (in)	N/A	N/A	N/A	1	0	N/A	6	N/A	N/A	N/A	N/A	12	N/A	N/A	N/A	N/A	N/A	N/A	N/A	4
Minimum Design Speed (mph)	N/A	N/A	N/A	N/A	50	N/A	N/A	N/A	N/A	N/A	N/A	N/A	55	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Install in No Passing Zones	N/A	N/A	N/A	Cont	Gap	Cont	Cont	Cont	Cont	Cont	N/A	Cont	Cont	Cont	Gap	N/A	Cont	N/A	N/A	Cont
Install in One-Way Passing Zones	N/A	N/A	N/A	Cont	Gap	Cont	No	N/A	No	No	N/A	Cont	Cont	No	No	N/A	Cont	N/A	N/A	Cont
Install in Two-Way Passing Zones	N/A	N/A	N/A	Cont	Gap	Cont	No	N/A	No	No	N/A	Cont	Cont	No	No	N/A	Cont	N/A	N/A	Cont
Cost ($/ft)	N/A	N/A	N/A	0.23	0.37	0.19	N/A	0.24	0.39	0.39	N/A	0.6	N/A	2	2	N/A	0.4	0.3	0.3	N/A

Table D- 8: CLRS Dimensions Ranked by CLRS Offset from the Pavement Centerline Joint

RS Offset (in)	0	0	0	0	0	0	0	0	0	0	10	11	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Length (in)	6.5	6.5	7	7	7	7	7	7	7	7	7	8	5	7	7	7	7	7	7	7
Width (in)	12	12	6	12	12	16	16	16	16	24	16	8	12	12	12	16	16	16	24	N/A
Depth (in)	0.5	0.5	0.375	0.5	0.6125	0.5	0.5	0.5	0.5	0.5	0.5	0.4375	0.315	0.4375	0.5	0.5	0.5	0.5	0.5	0.375
Spacing (in)	12	12	12	12	12	12	12	24	N/A	24	24	20	12	12	12	12	24	N/A	12	N/A
Number of Rows	1	1	1	1	1	1	1	1	2	1	2	2	N/A	1	1	1	1	1	1	1
FM Width (in)	N/A	N/A	N/A	N/A	N/A	48	72	N/A	48	N/A	12	8	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Gap/Continuous	Cont	Gap	Cont	Cont	Cont	Cont	Cont	Cont	Gap	Cont	Gap	Cont	Cont	Both	Cont	Cont	Cont	Cont	Cont	Both
Gap Length (in)	N/A	24	N/A	N/A	N/A	N/A	N/A	N/A	60	N/A	48	N/A	N/A	24	N/A	N/A	N/A	N/A	N/A	360
RS Section Length (in)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	180	N/A	24	N/A	N/A	12	N/A	N/A	N/A	N/A	N/A	120
Minimum Lane Width (ft)	N/A	N/A	12	N/A	12	N/A	N/A	10	N/A	N/A	11	11.3	12	10	N/A	N/A	N/A	N/A	11	N/A
Minimum Shoulder Width (ft)	N/A	N/A	4	N/A	N/A	N/A	N/A	0	N/A	N/A	3	3	N/A	2	N/A	N/A	N/A	N/A	4	6
Minimum Cross-Section Width (ft)	N/A	N/A	N/A	N/A	21	N/A	N/A	20	N/A	N/A	28	30	N/A	24	N/A	N/A	N/A	N/A	N/A	N/A
SRS Gap/Continuous	N/A	N/A	N/A	N/A	N/A	N/A	N/A	No	N/A	N/A	N/A	No	N/A	Cont	N/A	N/A	N/A	N/A	Both	Gap
Minimum SRS Offset (in)	N/A	N/A	1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0	6	N/A	N/A	N/A	12	4
Minimum Design Speed (mph)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	55	N/A	50	N/A	N/A	N/A	N/A	N/A	N/A
Install in No Passing Zones	N/A	N/A	Cont	Cont	Cont	Cont	Cont	Cont	N/A	Cont	Gap	Cont	N/A	Gap	Cont	N/A	N/A	N/A	Cont	Cont
Install in One-Way Passing Zones	N/A	N/A	Cont	Cont	N/A	No	No	No	N/A	Cont	No	Cont	N/A	Gap	No	N/A	N/A	N/A	Cont	Cont
Install in Two-Way Passing Zones	N/A	N/A	Cont	Cont	N/A	No	No	No	N/A	Cont	No	Cont	N/A	Gap	No	N/A	N/A	N/A	Cont	Cont
Cost ($/ft)	N/A	N/A	0.23	0.19	0.24	0.39	0.39	2	0.3	0.4	2	N/A	N/A	0.37	N/A	N/A	N/A	0.3	0.6	N/A

Table D- 9: CLRS Dimensions Ranked by Number of Rows per Pattern

Number of Rows	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	N/A
Length (in)	6.5	6.5	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	8	5
Width (in)	12	12	6	12	12	12	12	16	16	16	16	16	16	24	24	N/A	16	16	8	12
Depth (in)	0.5	0.5	0.375	0.4375	0.5	0.5	0.6125	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.375	0.5	0.5	0.4375	0.315
Spacing (in)	12	12	12	12	12	12	12	12	12	12	24	24	N/A	12	24	N/A	24	N/A	20	12
RS Offset (in)	0	0	0	N/A	0	N/A	0	0	0	N/A	0	N/A	N/A	N/A	0	N/A	10	0	11	N/A
FM Width (in)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	48	72	N/A	N/A	N/A	N/A	N/A	N/A	N/A	12	48	8	N/A
Gap/Continuous	Cont	Gap	Cont	Both	Cont	Cont	Cont	Cont	Cont	Cont	Cont	Cont	Cont	Cont	Cont	Both	Gap	Gap	Cont	Cont
Gap Length (in)	N/A	24	N/A	24	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	360	48	60	N/A	N/A
RS Section Length (in)	N/A	N/A	N/A	12	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	120	24	180	N/A	N/A
Minimum Lane Width (ft)	N/A	N/A	12	10	N/A	N/A	12	N/A	N/A	N/A	10	N/A	N/A	11	N/A	N/A	11	N/A	11.3	12
Minimum Shoulder Width (ft)	N/A	N/A	4	2	N/A	N/A	N/A	N/A	N/A	N/A	0	N/A	N/A	4	N/A	6	3	N/A	3	N/A
Minimum Cross-Section Width (ft)	N/A	N/A	N/A	24	N/A	N/A	21	N/A	N/A	N/A	20	N/A	N/A	N/A	N/A	N/A	28	N/A	30	N/A
SRS Gap/Continuous	N/A	N/A	N/A	Cont	N/A	N/A	N/A	N/A	N/A	N/A	No	N/A	N/A	Both	N/A	Gap	N/A	N/A	No	N/A
Minimum SRS Offset (in)	N/A	N/A	1	0	N/A	6	N/A	N/A	N/A	N/A	N/A	N/A	N/A	12	N/A	4	N/A	N/A	N/A	N/A
Minimum Design Speed (mph)	N/A	N/A	N/A	50	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	55	N/A
Install in No Passing Zones	N/A	N/A	Cont	Gap	Cont	Cont	Cont	Cont	Cont	N/A	Cont	N/A	N/A	Cont	Cont	Cont	Gap	N/A	Cont	N/A
Install in One-Way Passing Zones	N/A	N/A	Cont	Gap	Cont	No	N/A	No	No	N/A	No	N/A	N/A	Cont	Cont	Cont	No	N/A	Cont	N/A
Install in Two-Way Passing Zones	N/A	N/A	Cont	Gap	Cont	No	N/A	No	No	N/A	No	N/A	N/A	Cont	Cont	Cont	No	N/A	Cont	N/A
Cost ($/ft)	N/A	N/A	0.23	0.37	0.19	N/A	0.24	0.39	0.39	N/A	2	N/A	0.3	0.6	0.4	N/A	2	0.3	N/A	N/A

Table D- 10: CLRS Dimensions Ranked by the Flush Median Width

FM Width (in)	8	12	48	48	72	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Length (in)	8	7	7	7	7	5	6.5	6.5	7	7	7	7	7	7	7	7	7	7	7	7
Width (in)	8	16	16	16	16	12	12	12	6	12	12	12	12	16	16	16	16	24	24	N/A
Depth (in)	0.4375	0.5	0.5	0.5	0.5	0.315	0.5	0.5	0.375	0.4375	0.5	0.5	0.6125	0.5	0.5	0.5	0.5	0.5	0.5	0.375
Spacing (in)	20	24	12	N/A	12	12	12	12	12	12	12	12	12	12	24	24	N/A	12	24	N/A
RS Offset (in)	11	10	0	0	0	N/A	0	0	0	N/A	0	N/A	0	N/A	0	N/A	N/A	N/A	0	N/A
Number of Rows	2	2	1	2	1	N/A	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Gap/Continuous	Cont	Gap	Cont	Gap	Cont	Cont	Cont	Gap	Cont	Both	Cont	Cont	Cont	Cont	Cont	Cont	Cont	Cont	Cont	Both
Gap Length (in)	N/A	48	N/A	60	N/A	N/A	N/A	24	N/A	24	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	360
RS Section Length (in)	N/A	24	N/A	180	N/A	N/A	N/A	N/A	N/A	12	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	120
Minimum Lane Width (ft)	11.3	11	N/A	N/A	N/A	12	N/A	N/A	12	10	N/A	N/A	12	N/A	10	N/A	N/A	11	N/A	N/A
Minimum Shoulder Width (ft)	3	3	N/A	N/A	N/A	N/A	N/A	N/A	4	2	N/A	N/A	N/A	N/A	0	N/A	N/A	4	N/A	6
Minimum Cross-Section Width (ft)	30	28	N/A	N/A	N/A	N/A	N/A	N/A	N/A	24	N/A	N/A	21	N/A	20	N/A	N/A	N/A	N/A	N/A
SRS Gap/Continuous	No	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Cont	N/A	N/A	N/A	N/A	No	N/A	N/A	Both	N/A	Gap
Minimum SRS Offset (in)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1	0	N/A	6	N/A	N/A	N/A	N/A	N/A	12	N/A	4
Minimum Design Speed (mph)	55	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	50	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Install in No Passing Zones	Cont	Gap	Cont	N/A	Cont	N/A	N/A	N/A	Cont	Gap	Cont	Cont	Cont	N/A	Cont	N/A	N/A	Cont	Cont	Cont
Install in One-Way Passing Zones	Cont	No	No	N/A	No	N/A	N/A	N/A	Cont	Gap	Cont	No	N/A	N/A	No	N/A	N/A	Cont	Cont	Cont
Install in Two-Way Passing Zones	Cont	No	No	N/A	No	N/A	N/A	N/A	Cont	Gap	Cont	No	N/A	N/A	No	N/A	N/A	Cont	Cont	Cont
Cost ($/ft)	N/A	2	0.39	0.3	0.39	N/A	N/A	N/A	0.23	0.37	0.19	N/A	0.24	N/A	2	N/A	0.3	0.6	0.4	N/A

Table D- 11: CLRS Dimension Ranked by Continuous versus Gapped Patterns

Gap/Continuous	Cont	Cont	Cont	Cont	Cont	Cont	Cont	Cont	Cont	Cont	Cont	Cont	Cont	Cont	Cont	Gap	Gap	Gap	Both	Both
Gap Length (in)	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**24**	**48**	**60**	**24**	**360**
RS Section Length (in)	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**24**	**180**	**12**	**120**
Length (in)	5	6.5	7	7	7	7	7	7	7	7	7	7	7	7	8	6.5	7	7	7	7
Width (in)	12	12	6	12	12	12	16	16	16	16	16	16	24	24	8	12	16	16	12	N/A
Depth (in)	0.315	0.5	0.375	0.5	0.5	0.6125	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.4375	0.5	0.5	0.5	0.4375	0.375
Spacing (in)	12	12	12	12	12	12	12	12	12	24	24	N/A	12	24	20	12	24	N/A	12	N/A
RS Offset (in)	N/A	0	0	0	N/A	0	0	0	N/A	0	N/A	N/A	N/A	0	11	0	10	0	N/A	N/A
Number of Rows	N/A	1	1	1	1	1	1	1	1	1	1	1	1	1	2	1	2	2	1	1
FM Width (in)	N/A	N/A	N/A	N/A	N/A	N/A	48	72	N/A	N/A	N/A	N/A	N/A	N/A	8	N/A	12	48	N/A	N/A
Minimum Lane Width (ft)	12	N/A	12	N/A	N/A	12	N/A	N/A	N/A	10	N/A	N/A	11	N/A	11.3	N/A	11	N/A	10	N/A
Minimum Shoulder Width (ft)	N/A	N/A	4	N/A	N/A	N/A	N/A	N/A	N/A	0	N/A	N/A	4	N/A	3	N/A	3	N/A	2	6
Minimum Cross-Section Width (ft)	N/A	N/A	N/A	N/A	N/A	21	N/A	N/A	N/A	20	N/A	N/A	N/A	N/A	30	N/A	28	N/A	24	N/A
SRS Gap/Continuous	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	No	N/A	N/A	Both	N/A	No	N/A	N/A	N/A	Cont	Gap
Minimum SRS Offset (in)	N/A	N/A	1	N/A	6	N/A	N/A	N/A	N/A	N/A	N/A	N/A	12	N/A	N/A	N/A	N/A	N/A	0	4
Minimum Design Speed (mph)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	55	N/A	N/A	N/A	50	N/A
Install in No Passing Zones	N/A	N/A	Cont	Cont	Cont	Cont	Cont	Cont	N/A	Cont	N/A	N/A	Cont	Cont	Cont	N/A	Gap	N/A	Gap	Cont
Install in One-Way Passing Zones	N/A	N/A	Cont	Cont	No	N/A	No	No	N/A	No	N/A	N/A	Cont	Cont	Cont	N/A	No	N/A	Gap	Cont
Install in Two-Way Passing Zones	N/A	N/A	Cont	Cont	No	N/A	No	No	N/A	No	N/A	N/A	Cont	Cont	Cont	N/A	No	N/A	Gap	Cont
Cost ($/ft)	N/A	N/A	0.23	0.19	N/A	0.24	0.39	0.39	N/A	2	N/A	0.3	0.6	0.4	N/A	N/A	2	0.3	0.37	N/A

Table D- 12: CLRS Dimensions Ranked by Minimum Lane Width

Minimum Lane Width (ft)	**10**	**10**	**11**	**11**	**11.3**	**12**	**12**	**12**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**
Length (in)	7	7	7	7	8	7	7	5	6.5	6.5	7	7	7	7	7	7	7	7	7	7
Width (in)	12	16	16	24	8	6	12	12	12	12	12	12	16	16	16	16	16	16	24	N/A
Depth (in)	0.4375	0.5	0.5	0.5	0.4375	0.375	0.6125	0.315	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.375
Spacing (in)	12	24	24	12	20	12	12	12	12	12	12	12	12	12	12	24	N/A	N/A	24	N/A
RS Offset (in)	N/A	0	10	N/A	11	0	0	N/A	0	0	0	N/A	0	0	N/A	N/A	0	N/A	0	N/A
Number of Rows	1	1	2	1	2	1	1	N/A	1	1	1	1	1	1	1	1	2	1	1	1
FM Width (in)	N/A	N/A	12	N/A	8	N/A	N/A	N/A	N/A	N/A	N/A	N/A	48	72	N/A	N/A	48	N/A	N/A	N/A
Gap/Continuous	Both	Cont	Gap	Cont	Cont	Cont	Cont	Cont	Cont	Gap	Cont	Cont	Cont	Cont	Cont	Cont	Gap	Cont	Cont	Both
Gap Length (in)	24	N/A	48	N/A	N/A	N/A	N/A	N/A	N/A	24	N/A	N/A	N/A	N/A	N/A	N/A	60	N/A	N/A	360
RS Section Length (in)	12	N/A	24	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	180	N/A	N/A	120
Minimum Shoulder Width (ft)	2	0	3	4	3	4	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	6
Minimum Cross-Section Width (ft)	24	20	28	N/A	30	N/A	21	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SRS Gap/Continuous	Cont	No	N/A	Both	No	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Gap
Minimum SRS Offset (in)	0	N/A	N/A	12	N/A	1	N/A	N/A	N/A	N/A	N/A	6	N/A	N/A	N/A	N/A	N/A	N/A	N/A	4
Minimum Design Speed (mph)	50	N/A	N/A	N/A	55	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Install in No Passing Zones	Gap	Cont	Gap	Cont	Cont	Cont	Cont	N/A	N/A	N/A	Cont	Cont	Cont	Cont	N/A	N/A	N/A	N/A	Cont	Cont
Install in One-Way Passing Zones	Gap	No	No	Cont	Cont	Cont	N/A	N/A	N/A	N/A	Cont	No	No	No	N/A	N/A	N/A	N/A	Cont	Cont
Install in Two-Way Passing Zones	Gap	No	No	Cont	Cont	Cont	N/A	N/A	N/A	N/A	Cont	No	No	No	N/A	N/A	N/A	N/A	Cont	Cont
Cost ($/ft)	0.37	2	2	0.6	N/A	0.23	0.24	N/A	N/A	N/A	0.19	N/A	0.39	0.39	N/A	N/A	0.3	0.3	0.4	N/A

Table D- 13: CLRS Dimensions Ranked by Minimum Shoulder Width

Minimum Shoulder Width (ft)	**0**	**2**	**3**	**3**	**4**	**4**	**6**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**
Length (in)	7	7	7	8	7	7	7	5	6.5	6.5	7	7	7	7	7	7	7	7	7	7
Width (in)	16	12	16	8	6	24	N/A	12	12	12	12	12	12	16	16	16	16	16	16	24
Depth (in)	0.5	0.4375	0.5	0.4375	0.375	0.5	0.375	0.315	0.5	0.5	0.5	0.5	0.6125	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Spacing (in)	24	12	24	20	12	12	N/A	12	12	12	12	12	12	12	12	12	24	N/A	N/A	24
RS Offset (in)	0	N/A	10	11	0	N/A	N/A	N/A	0	0	0	N/A	0	0	0	N/A	N/A	0	N/A	0
Number of Rows	1	1	2	2	1	1	1	N/A	1	1	1	1	1	1	1	1	1	2	1	1
FM Width (in)	N/A	N/A	12	8	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	48	72	N/A	N/A	48	N/A	N/A
Gap/Continuous	Cont	Both	Gap	Cont	Cont	Cont	Both	Cont	Cont	Gap	Cont	Cont	Cont	Cont	Cont	Cont	Cont	Gap	Cont	Cont
Gap Length (in)	N/A	24	48	N/A	N/A	N/A	360	N/A	N/A	24	N/A	N/A	N/A	N/A	N/A	N/A	N/A	60	N/A	N/A
RS Section Length (in)	N/A	12	24	N/A	N/A	N/A	120	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	180	N/A	N/A
Minimum Lane Width (ft)	10	10	11	11.3	12	11	N/A	12	N/A	N/A	N/A	N/A	12	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Minimum Cross-Section Width (ft)	20	24	28	30	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	21	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SRS Gap/Continuous	No	Cont	N/A	No	N/A	Both	Gap	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Minimum SRS Offset (in)	N/A	0	N/A	N/A	1	12	4	N/A	N/A	N/A	N/A	6	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Minimum Design Speed (mph)	N/A	50	N/A	55	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Install in No Passing Zones	Cont	Gap	Gap	Cont	Cont	Cont	Cont	N/A	N/A	N/A	Cont	Cont	Cont	Cont	Cont	N/A	N/A	N/A	N/A	Cont
Install in One-Way Passing Zones	No	Gap	No	Cont	Cont	Cont	Cont	N/A	N/A	N/A	Cont	No	N/A	No	No	N/A	N/A	N/A	N/A	Cont
Install in Two-Way Passing Zones	No	Gap	No	Cont	Cont	Cont	Cont	N/A	N/A	N/A	Cont	No	N/A	No	No	N/A	N/A	N/A	N/A	Cont
Cost ($/ft)	2	0.37	2	N/A	0.23	0.6	N/A	N/A	N/A	N/A	0.19	N/A	0.24	0.39	0.39	N/A	N/A	0.3	0.3	0.4

Table D- 14: CLRS Dimensions Ranked by Minimum Cross Section Width

Minimum Cross-Section Width (ft)	20	21	24	28	30	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Length (in)	7	7	7	7	8	5	6.5	6.5	7	7	7	7	7	7	7	7	7	7	7	7
Width (in)	16	12	12	16	8	12	12	12	6	12	12	16	16	16	16	16	16	24	24	N/A
Depth (in)	0.5	0.6125	0.4375	0.5	0.4375	0.315	0.5	0.5	0.375	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.375
Spacing (in)	24	12	12	24	20	12	12	12	12	12	12	12	12	12	24	N/A	N/A	12	24	N/A
RS Offset (in)	0	0	N/A	10	11	N/A	0	0	0	0	N/A	0	0	N/A	N/A	0	N/A	N/A	0	N/A
Number of Rows	1	1	1	2	2	N/A	1	1	1	1	1	1	1	1	1	2	1	1	1	1
FM Width (in)	N/A	N/A	N/A	12	8	N/A	N/A	N/A	N/A	N/A	N/A	48	72	N/A	N/A	48	N/A	N/A	N/A	N/A
Gap/Continuous	Cont	Cont	Both	Gap	Cont	Cont	Cont	Gap	Cont	Cont	Cont	Cont	Cont	Cont	Cont	Gap	Cont	Cont	Cont	Both
Gap Length (in)	N/A	N/A	24	48	N/A	N/A	N/A	24	N/A	N/A	N/A	N/A	N/A	N/A	N/A	60	N/A	N/A	N/A	360
RS Section Length (in)	N/A	N/A	12	24	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	180	N/A	N/A	N/A	120
Minimum Lane Width (ft)	10	12	10	11	11.3	12	N/A	N/A	12	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	11	N/A	N/A
Minimum Shoulder Width (ft)	0	N/A	2	3	3	N/A	N/A	N/A	4	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	4	N/A	6
SRS Gap/Continuous	No	N/A	Cont	N/A	No	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Both	N/A	Gap
Minimum SRS Offset (in)	N/A	N/A	0	N/A	N/A	N/A	N/A	N/A	1	N/A	6	N/A	N/A	N/A	N/A	N/A	N/A	12	N/A	4
Minimum Design Speed (mph)	N/A	N/A	50	N/A	55	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Install in No Passing Zones	Cont	Cont	Gap	Gap	Cont	N/A	N/A	N/A	Cont	Cont	Cont	Cont	Cont	N/A	N/A	N/A	N/A	Cont	Cont	Cont
Install in One-Way Passing Zones	No	N/A	Gap	No	Cont	N/A	N/A	N/A	Cont	Cont	No	No	No	N/A	N/A	N/A	N/A	Cont	Cont	Cont
Install in Two-Way Passing Zones	No	N/A	Gap	No	Cont	N/A	N/A	N/A	Cont	Cont	No	No	No	N/A	N/A	N/A	N/A	Cont	Cont	Cont
Cost ($/ft)	2	0.24	0.37	2	N/A	N/A	N/A	N/A	0.23	0.19	N/A	0.39	0.39	N/A	N/A	0.3	0.3	0.6	0.4	N/A

Table D- 15: CLRS Dimensions Ranked by Shoulder Rumble Strip Patterns

SRS Gap/Continuous	Cont	Gap	Both	No	No	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Length (in)	7	7	7	7	8	5	6.5	6.5	7	7	7	7	7	7	7	7	7	7	7	7
Width (in)	12	N/A	24	16	8	12	12	12	6	12	12	12	16	16	16	16	16	16	16	24
Depth (in)	0.4375	0.375	0.5	0.5	0.4375	0.315	0.5	0.5	0.375	0.5	0.5	0.6125	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Spacing (in)	12	N/A	12	24	20	12	12	12	12	12	12	12	12	12	12	24	24	N/A	N/A	24
RS Offset (in)	N/A	N/A	N/A	0	11	N/A	0	0	0	0	N/A	0	0	0	N/A	10	N/A	0	N/A	0
Number of Rows	1	1	1	1	2	N/A	1	1	1	1	1	1	1	1	1	2	1	2	1	1
FM Width (in)	N/A	N/A	N/A	N/A	8	N/A	N/A	N/A	N/A	N/A	N/A	N/A	48	72	N/A	12	N/A	48	N/A	N/A
Gap/Continuous	Both	Both	Cont	Cont	Cont	Cont	Cont	Gap	Cont	Cont	Cont	Cont	Cont	Cont	Cont	Gap	Cont	Gap	Cont	Cont
Gap Length (in)	24	360	N/A	N/A	N/A	N/A	N/A	24	N/A	N/A	N/A	N/A	N/A	N/A	N/A	48	N/A	60	N/A	N/A
RS Section Length (in)	12	120	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	24	N/A	180	N/A	N/A
Minimum Lane Width (ft)	10	N/A	11	10	11.3	12	N/A	N/A	12	N/A	N/A	12	N/A	N/A	N/A	11	N/A	N/A	N/A	N/A
Minimum Shoulder Width (ft)	2	6	4	0	3	N/A	N/A	N/A	4	N/A	N/A	N/A	N/A	N/A	N/A	3	N/A	N/A	N/A	N/A
Minimum Cross-Section Width (ft)	24	N/A	N/A	20	30	N/A	N/A	N/A	N/A	N/A	N/A	21	N/A	N/A	N/A	28	N/A	N/A	N/A	N/A
Minimum SRS Offset (in)	0	4	12	N/A	N/A	N/A	N/A	N/A	1	N/A	6	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Minimum Design Speed (mph)	50	N/A	N/A	N/A	55	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Install in No Passing Zones	Gap	Cont	Cont	Cont	Cont	N/A	N/A	N/A	Cont	Cont	Cont	Cont	Cont	Cont	N/A	Gap	N/A	N/A	N/A	Cont
Install in One-Way Passing Zones	Gap	Cont	Cont	No	Cont	N/A	N/A	N/A	Cont	Cont	No	N/A	No	No	N/A	No	N/A	N/A	N/A	Cont
Install in Two-Way Passing Zones	Gap	Cont	Cont	No	Cont	N/A	N/A	N/A	Cont	Cont	No	N/A	No	No	N/A	No	N/A	N/A	N/A	Cont
Cost ($/ft)	0.37	N/A	0.6	2	N/A	N/A	N/A	N/A	0.23	0.19	N/A	0.24	0.39	0.39	N/A	2	N/A	0.3	0.3	0.4

Table D- 16: CLRS Dimensions Ranked by Minimum Shoulder Rumble Strip Offset

Minimum SRS Offset (in)	**0**	**1**	**4**	**6**	**12**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**
Length (in)	7	7	7	7	7	5	6.5	6.5	7	7	7	7	7	7	7	7	7	7	7	8
Width (in)	12	6	N/A	12	24	12	12	12	12	12	16	16	16	16	16	16	16	16	24	8
Depth (in)	0.4375	0.375	0.375	0.5	0.5	0.315	0.5	0.5	0.5	0.6125	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.4375
Spacing (in)	12	12	N/A	12	12	12	12	12	12	12	12	12	12	24	24	24	N/A	N/A	24	20
RS Offset (in)	N/A	0	N/A	N/A	N/A	N/A	0	0	0	0	0	0	N/A	0	10	N/A	0	N/A	0	11
Number of Rows	1	1	1	1	1	N/A	1	1	1	1	1	1	1	1	2	1	2	1	1	2
FM Width (in)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	48	72	N/A	N/A	12	N/A	48	N/A	N/A	8
Gap/Continuous	Both	Cont	Both	Cont	Cont	Cont	Cont	Gap	Cont	Cont	Cont	Cont	Cont	Cont	Gap	Cont	Gap	Cont	Cont	Cont
Gap Length (in)	24	N/A	360	N/A	N/A	N/A	N/A	24	N/A	N/A	N/A	N/A	N/A	N/A	48	N/A	60	N/A	N/A	N/A
RS Section Length (in)	12	N/A	120	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	24	N/A	180	N/A	N/A	N/A
Minimum Lane Width (ft)	10	12	N/A	N/A	11	12	N/A	N/A	N/A	12	N/A	N/A	N/A	10	11	N/A	N/A	N/A	N/A	11.3
Minimum Shoulder Width (ft)	2	4	6	N/A	4	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0	3	N/A	N/A	N/A	N/A	3
Minimum Cross-Section Width (ft)	24	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	21	N/A	N/A	N/A	20	28	N/A	N/A	N/A	N/A	30
SRS Gap/Continuous	Cont	N/A	Gap	N/A	Both	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	No	N/A	N/A	N/A	N/A	N/A	No
Minimum Design Speed (mph)	50	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	55
Install in No Passing Zones	Gap	Cont	Cont	Cont	Cont	N/A	N/A	N/A	Cont	Cont	Cont	Cont	N/A	Cont	Gap	N/A	N/A	N/A	Cont	Cont
Install in One-Way Passing Zones	Gap	Cont	Cont	No	Cont	N/A	N/A	N/A	Cont	N/A	No	No	N/A	No	No	N/A	N/A	N/A	Cont	Cont
Install in Two-Way Passing Zones	Gap	Cont	Cont	No	Cont	N/A	N/A	N/A	Cont	N/A	No	No	N/A	No	No	N/A	N/A	N/A	Cont	Cont
Cost ($/ft)	0.37	0.23	N/A	N/A	0.6	N/A	N/A	N/A	0.19	0.24	0.39	0.39	N/A	2	2	N/A	0.3	0.3	0.4	N/A

Table D- 17: CLRS Dimensions Ranked by Minimum Design Speed

Minimum Design Speed (mph)	**50**	**55**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**
Length (in)	7	8	5	6.5	6.5	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
Width (in)	12	8	12	12	12	6	12	12	12	16	16	16	16	16	16	16	16	24	24	N/A
Depth (in)	0.4375	0.4375	0.315	0.5	0.5	0.375	0.5	0.5	0.6125	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.375
Spacing (in)	12	20	12	12	12	12	12	12	12	12	12	12	24	24	24	N/A	N/A	12	24	N/A
RS Offset (in)	N/A	11	N/A	0	0	0	0	N/A	0	0	0	N/A	0	10	N/A	0	N/A	N/A	0	N/A
Number of Rows	1	2	N/A	1	1	1	1	1	1	1	1	1	1	2	1	2	1	1	1	1
FM Width (in)	N/A	8	N/A	N/A	N/A	N/A	N/A	N/A	N/A	48	72	N/A	N/A	12	N/A	48	N/A	N/A	N/A	N/A
Gap/Continuous	Both	Cont	Cont	Cont	Gap	Cont	Cont	Cont	Cont	Cont	Cont	Cont	Cont	Gap	Cont	Gap	Cont	Cont	Cont	Both
Gap Length (in)	24	N/A	N/A	N/A	24	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	48	N/A	60	N/A	N/A	N/A	360
RS Section Length (in)	12	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	24	N/A	180	N/A	N/A	N/A	120
Minimum Lane Width (ft)	10	11.3	12	N/A	N/A	12	N/A	N/A	12	N/A	N/A	N/A	10	11	N/A	N/A	N/A	11	N/A	N/A
Minimum Shoulder Width (ft)	2	3	N/A	N/A	N/A	4	N/A	N/A	N/A	N/A	N/A	N/A	0	3	N/A	N/A	N/A	4	N/A	6
Minimum Cross-Section Width (ft)	24	30	N/A	N/A	N/A	N/A	N/A	N/A	21	N/A	N/A	N/A	20	28	N/A	N/A	N/A	N/A	N/A	N/A
SRS Gap/Continuous	Cont	No	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	No	N/A	N/A	N/A	N/A	Both	N/A	Gap
Minimum SRS Offset (in)	0	N/A	N/A	N/A	N/A	1	N/A	6	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	12	N/A	4
Install in No Passing Zones	Gap	Cont	N/A	N/A	N/A	Cont	Cont	Cont	Cont	Cont	Cont	N/A	Cont	Gap	N/A	N/A	N/A	Cont	Cont	Cont
Install in One-Way Passing Zones	Gap	Cont	N/A	N/A	N/A	Cont	Cont	No	N/A	No	No	N/A	No	No	N/A	N/A	N/A	Cont	Cont	Cont
Install in Two-Way Passing Zones	Gap	Cont	N/A	N/A	N/A	Cont	Cont	No	N/A	No	No	N/A	No	No	N/A	N/A	N/A	Cont	Cont	Cont
Cost ($/ft)	0.37	N/A	N/A	N/A	N/A	0.23	0.19	N/A	0.24	0.39	0.39	N/A	2	2	N/A	0.3	0.3	0.6	0.4	N/A

Table D- 18: CLRS Dimensions Ranked by Installation in No Passing Zones

Install in No Passing Zones	Cont	Cont	Cont	Cont	Cont	Cont	Cont	Cont	Cont	Cont	Cont	Gap	Gap	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Length (in)	7	7	7	7	7	7	7	7	7	7	8	7	7	5	6.5	6.5	7	7	7	7
Width (in)	6	12	12	12	16	16	16	24	24	N/A	8	12	16	12	12	12	16	16	16	16
Depth (in)	0.375	0.5	0.5	0.6125	0.5	0.5	0.5	0.5	0.5	0.375	0.4375	0.4375	0.5	0.315	0.5	0.5	0.5	0.5	0.5	0.5
Spacing (in)	12	12	12	12	12	12	24	12	24	N/A	20	12	24	12	12	12	12	24	N/A	N/A
RS Offset (in)	0	0	N/A	0	0	0	0	N/A	0	N/A	11	N/A	10	N/A	0	0	N/A	N/A	0	N/A
Number of Rows	1	1	1	1	1	1	1	1	1	1	2	1	2	N/A	1	1	1	1	2	1
FM Width (in)	N/A	N/A	N/A	N/A	48	72	N/A	N/A	N/A	N/A	8	N/A	12	N/A	N/A	N/A	N/A	N/A	48	N/A
Gap/Continuous	Cont	Cont	Cont	Cont	Cont	Cont	Cont	Cont	Cont	Both	Cont	Both	Gap	Cont	Cont	Gap	Cont	Cont	Gap	Cont
Gap Length (in)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	360	N/A	24	48	N/A	N/A	24	N/A	N/A	60	N/A
RS Section Length (in)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	120	N/A	12	24	N/A	N/A	N/A	N/A	N/A	180	N/A
Minimum Lane Width (ft)	12	N/A	N/A	12	N/A	N/A	10	11	N/A	N/A	11.3	10	11	12	N/A	N/A	N/A	N/A	N/A	N/A
Minimum Shoulder Width (ft)	4	N/A	N/A	N/A	N/A	N/A	0	4	N/A	6	3	2	3	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Minimum Cross-Section Width (ft)	N/A	N/A	N/A	21	N/A	N/A	20	N/A	N/A	N/A	30	24	28	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SRS Gap/Continuous	N/A	N/A	N/A	N/A	N/A	N/A	No	Both	N/A	Gap	No	Cont	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Minimum SRS Offset (in)	1	N/A	6	N/A	N/A	N/A	N/A	12	N/A	4	N/A	0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Minimum Design Speed (mph)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	55	50	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Install in One-Way Passing Zones	Cont	Cont	No	N/A	No	No	No	Cont	Cont	Cont	Cont	Gap	No	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Install in Two-Way Passing Zones	Cont	Cont	No	N/A	No	No	No	Cont	Cont	Cont	Cont	Gap	No	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Cost ($/ft)	0.23	0.19	N/A	0.24	0.39	0.39	2	0.6	0.4	N/A	N/A	0.37	2	N/A	N/A	N/A	N/A	N/A	0.3	0.3

Table D- 19: CLRS Dimensions Ranked by Installation in One-Way Passing Zones

Install in One-Way Passing Zones	Cont	Cont	Cont	Cont	Cont	Cont	Gap	No	No	No	No	No	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Length (in)	7	7	7	7	7	8	7	7	7	7	7	7	5	6.5	6.5	7	7	7	7	7
Width (in)	6	12	24	24	N/A	8	12	12	16	16	16	16	12	12	12	12	16	16	16	16
Depth (in)	0.375	0.5	0.5	0.5	0.375	0.4375	0.4375	0.5	0.5	0.5	0.5	0.5	0.315	0.5	0.5	0.6125	0.5	0.5	0.5	0.5
Spacing (in)	12	12	12	24	N/A	20	12	12	12	12	24	24	12	12	12	12	12	24	N/A	N/A
RS Offset (in)	0	0	N/A	0	N/A	11	N/A	N/A	0	0	0	10	N/A	0	0	0	N/A	N/A	0	N/A
Number of Rows	1	1	1	1	1	2	1	1	1	1	1	2	N/A	1	1	1	1	1	2	1
FM Width (in)	N/A	N/A	N/A	N/A	N/A	8	N/A	N/A	48	72	N/A	12	N/A	N/A	N/A	N/A	N/A	N/A	48	N/A
Gap/Continuous	Cont	Cont	Cont	Cont	Both	Cont	Both	Cont	Cont	Cont	Cont	Gap	Cont	Cont	Gap	Cont	Cont	Cont	Gap	Cont
Gap Length (in)	N/A	N/A	N/A	N/A	360	N/A	24	N/A	N/A	N/A	N/A	48	N/A	N/A	24	N/A	N/A	N/A	60	N/A
RS Section Length (in)	N/A	N/A	N/A	N/A	120	N/A	12	N/A	N/A	N/A	N/A	24	N/A	N/A	N/A	N/A	N/A	N/A	180	N/A
Minimum Lane Width (ft)	12	N/A	11	N/A	N/A	11.3	10	N/A	N/A	N/A	10	11	12	N/A	N/A	12	N/A	N/A	N/A	N/A
Minimum Shoulder Width (ft)	4	N/A	4	N/A	6	3	2	N/A	N/A	N/A	0	3	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Minimum Cross-Section Width (ft)	N/A	N/A	N/A	N/A	N/A	30	24	N/A	N/A	N/A	20	28	N/A	N/A	N/A	21	N/A	N/A	N/A	N/A
SRS Gap/Continuous	N/A	N/A	Both	N/A	Gap	No	Cont	N/A	N/A	N/A	No	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Minimum SRS Offset (in)	1	N/A	12	N/A	4	N/A	0	6	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Minimum Design Speed (mph)	N/A	N/A	N/A	N/A	N/A	55	50	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Install in No Passing Zones	Cont	Cont	Cont	Cont	Cont	Cont	Gap	Cont	Cont	Cont	Cont	Gap	N/A	N/A	N/A	Cont	N/A	N/A	N/A	N/A
Install in Two-Way Passing Zones	Cont	Cont	Cont	Cont	Cont	Cont	Gap	No	No	No	No	No	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Cost ($/ft)	0.23	0.19	0.6	0.4	N/A	N/A	0.37	N/A	0.39	0.39	2	2	N/A	N/A	N/A	0.24	N/A	N/A	0.3	0.3

APPENDIX E: DRAFT GUIDELINES FOR CENTERLINE RUMBLE STRIPS

Guidelines for Centerline Rumble Strips – Draft June 4, 2005

Introduction

Centerline rumble strips (CLRS) are a treatment method for undivided two-way roads aimed at reducing or preventing potential non-intersection crossover crashes. These crashes include head-on, sideswipe and run-off-the-road in the case where the vehicle leaves the road from the opposing shoulder. This is the primary reason for installing CLRS. Another reason for installing CLRS is for road sections that have a high occurrence of poor visibility conditions due to fog, dust clouds, rain and light snow.

The effectiveness of CLRS is based upon the ability of the rumble strips to create audible and vibratory warnings to stimulate a driver.

Centerline rumble strips should be considered when a median barrier is not feasible. Feasibility of CLRS installations depend upon the available right of way, cost, and the frequency of crossover crashes.

General Guidelines to CLRS Installation

The following guidelines apply to all installations of centerline rumble strips (CLRS)

1. The State/Region Traffic Engineer's approval is required for CLRS installation
2. A highway section's crash data indicates a significant number of crossover crashes that may be remedied by installing CLRS. This significant number of crossover crashes is defined by the Utah Department of Transportation.
3. A highway has a minimum posted speed of 50 mph. Meaning, CLRS may be installed on any rural, undivided highway with a speed limit of 50 mph or greater.
4. Use milled rumble strips unless an alternative method may be justified. See Material Specifications - Milled Rumble Strips
5. If pavement marking replacement is required, a durable pavement marking system should be used. See Specifications – Pavement Markings
6. Do not install CLRS:
    a. On bridge decks.
    b. An adequate no CLRS zone should be provided through intersections with public roads to allow vehicles to make safe left-turns without driving onto the CLRS. The inside tracking of heavy trucks and tractor trailers should be considered. Left turns include vehicles exiting the highway by a left turn and vehicles entering the highway by a left turn.
    c. Directly in front of residences and businesses along the highway without prior consultation with the occupants. Determine a safe distance from a residency or business where noise pollution is reduced to acceptable levels.
7. Removal of CLRS from an existing installation may occur if a documented reason is provided or an alternative safety measure replaces the CLRS.

Geometric Specifications

Every highway has different characteristics. In planning a CLRS project, the following considerations should be addressed.

1. Shoulder rumble strip qualifications are independent of CLRS qualifications. Therefore, if the requirements of shoulder rumble strips and CLRS are met for a road section, shoulder rumble strips and CLRS should be installed. However in the case where both shoulder rumble strips and CLRS qualify, shoulder rumble strip geometry should be designed to accommodate the CLRS geometry since median space may be a limiting factor.
2. Drivable lane width should be greater than 10 feet. This width is defined as the dimension between the lane-side edges of CLRS and shoulder pavement marking lines (Hood 2002).
3. Dimensional considerations may reflect national trends (see Table E-1).

Table E-1: State of the Practice Survey CLRS Dimensions

Dimension	Maximum	Minimum	Mode	Average
Length (in)	8	5	7	6.900
Width (in)	24	6	16	14.421
Depth (in)	0.6125	0.315	0.5	0.478
Spacing (in)	24	12	12	15.294
CLRS Offset (in)	11	0	0	1.750
Number of Rows	2	1	1	1.158
Flush Median Width (in)	72	8	48	37.600

(Saito and Richards 2005)

4. The widest CLRS groove pattern possible should be used. This maximizes the time a drifting vehicle interacts with the CLRS (Perrilo 1998). This also permits wider tires or double tires to have a more effective reaction with the rumble strips (Surface Preparation Technologies, Undated).
5. Rumble strips should be installed as close to the pavement marking line as practical (FHWA 2001). Pavement markings may be applied over, adjacent, or offset from the CLRS grooves. Two rows of CLRS should be installed if the painted median width is greater than two times the design CLRS groove width plus adequate lateral spacing (see Table E-2). Refer to Material Specifications: Pavement Markings.

Table E-2: Potential CLRS Installations for Various Flush Median Widths

Minimum Exterior Dimension of Flush Median Width (inches)	Pavement Marking Location with respect to CLRS								
	Markings placed over CLRS			One-row of Markings offset from CLRS			Two-rows of markings offset from CLRS		
	Common CLRS Groove Width (inches)								
	12	16	24	12	16	24	12	16	24
	Numbers of Rows of CLRS per Flush Median Width								
12	1								
16	1	1							
24	1	1	1						
28	2	1	1	1					
32	2	1	1	1	1				
36	2	2	1	1	1				
40	2	2	1	1	1	1			
44	2	2	1	2	1	1	1		
48	2	2	1	2	1	1	1	1	
52	2	2	2	2	2	1	1	1	
56	2	2	2	2	2	1	1	1	1
60	2	2	2	2	2	1	2	1	1
68	2	2	2	2	2	2	2	2	1
≥ 84	2	2	2	2	2	2	2	2	2
Assumed 4 inch lateral space between pavement markings and CLRS grooves (see Figure E-1)									

6. Continuous CLRS installation patterns are appropriate on a highway sections with no passing zones (see
7. **Figure E-1**).
8. Continuous and gapped CLRS installation patterns are appropriate on a highway sections with one-way passing zones or two-way passing zones (see
9. **Figure E-1** and **Figure E-2**).
10. A gapped pattern may be preferable in passing zones for passing considerations. Safety considerations may require a continuous pattern. As of May 2005, there were no comparative crash reduction results between continuous and gapped CLRS patterns. By logical inference, a gapped pattern provides a reduced warning that may be less effective.

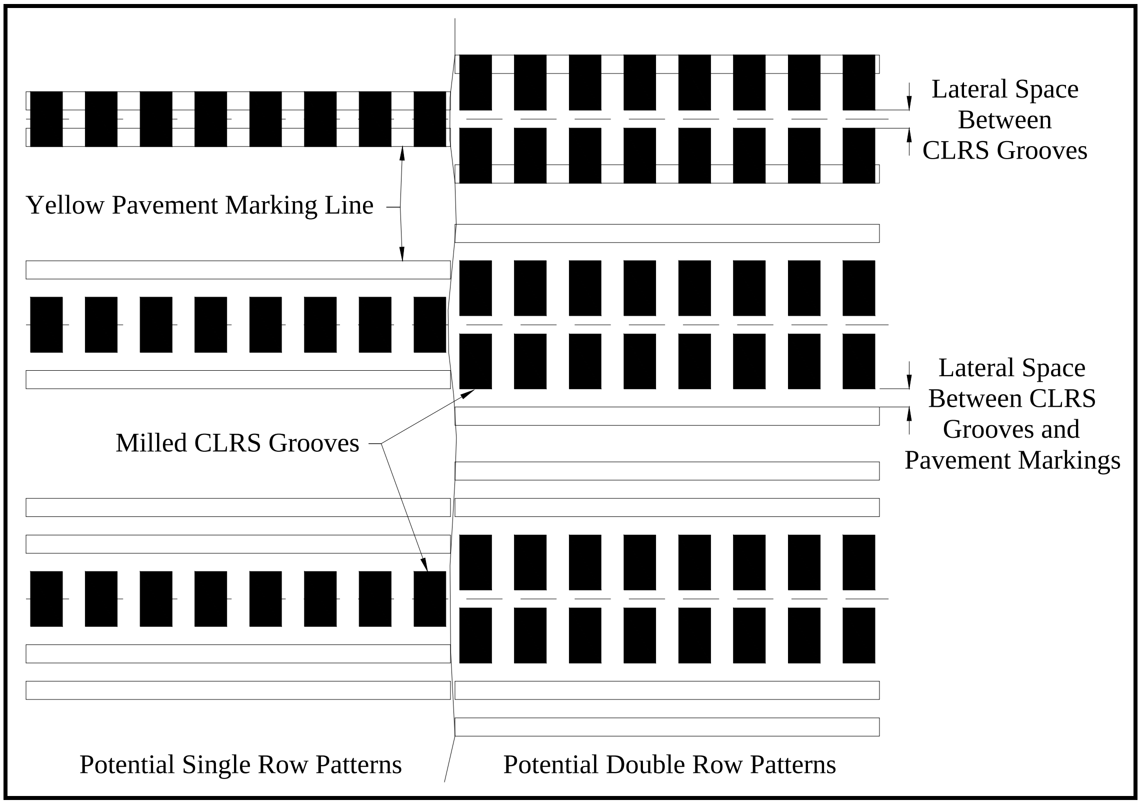

Figure E-1: Potential Continuous CLRS Patterns with Pavement Markings

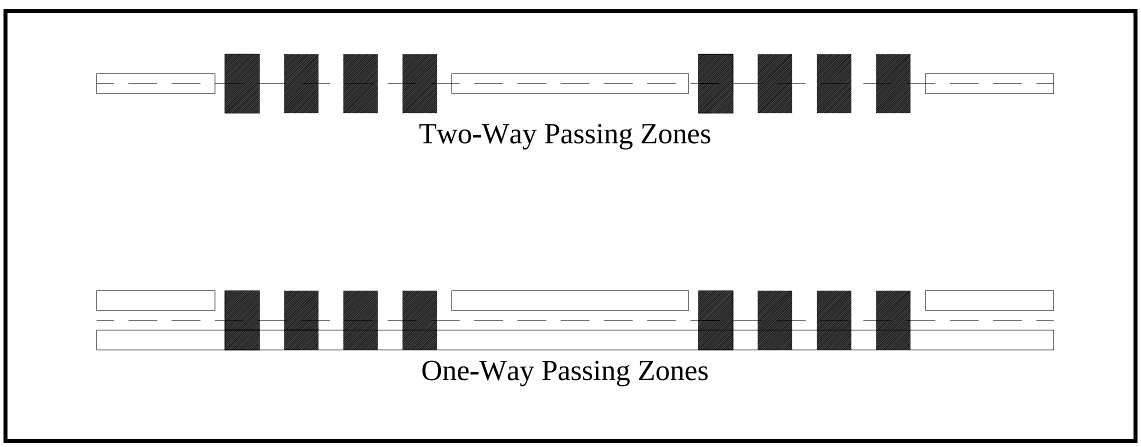

Figure E-2: Potential Gapped CLRS Patterns

Material Specifications

Milled Rumble Strips

- Centerline rumble strips should be installed by milling or grinding the grooves from the pavement surface. This is the primary method for CLRS installation.

- This method can be installed on new or old pavements. Old pavements should be in good condition for CLRS retrofit projects, otherwise, resurfacing of the pavement is required. Refer to General Guidelines to CLRS Installation item 1.
- Milled CLRS require a minimum bituminous pavement layer thickness of 2.5 inches (Russell and Rys 2005; FHWA 2001). Pavement may deteriorate more quickly if rumble strips are installed in marginal or distressed pavements (Alaska 2001).
- This method is minimally affected by snow-removal.

Raised Profile or Inverted Rumble Strips

- Raised pavement markers by themselves apparently are not very effective (Perrilo 1998)
- This method cannot be installed on highway where snow removal occurs.

Rolled Rumble Strips

- This method of installation is discouraged. This method is not as effective as milled rumble strips and installation requirements are more restricted (FHWA 2001; Perrilo 1998).

Pavement Markings

- Pavement markings should comply to MUTCD Section 3B: Yellow Centerline Pavement Markings and Warrants (FHWA 2003)
- Markings applied directly over the rumble strip create a profiled marking system improving the reflective qualities of the markings. However, additional maintenance may be required to remove sand, snow or debris that may accumulate in the CLRS grooves that may cover the markings. (Filcek et al. 2004)
- Painted pavement markings may be installed directly over the rumble strips or to the side of the rumble strips. Profiled thermoplastic tape does not need to be installed directly over the rumble strips.
- When snow removal is a factor, thermoplastic tape should not be installed over the CLRS grooves unless it is adequately recessed to avoid tearing from the contact of a snow plow blade, and edges of the CLRS groove.

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