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FINAL REPORT

REDUCING CROSSOVER ACCIDENTS ON KANSAS HIGHWAYS USING MILLED CENTERLINE RUMBLE STRIPS

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16 Abstract

In the USA, shoulder rumble strips are very common. It is estimated that they reduce run-of-the-road crashes up to 25%. The Kansas Department of Transportation (KDOT) has installed rumble strips on the shoulders of almost all state highways in the state. However, Kansas has several miles of two-lane highways with no shoulder. These highways have a number of single vehicle run-of-the-road crashes (both sides) as well as crashes from cars going across the centerline and colliding with on-coming vehicles (crossover crashes). Some U.S. states have been using or experimenting with centerline rumble strips (CLRS). In most states that use them, they are used only on no-passing sections or curves. KDOT contracted with Kansas State University (KSU) to survey other states and summarize their experience and to develop a research design to evaluate KDOT test installations. KSU surveyed U.S. and Canadian provinces and found no serious negative problems with CLRS and recommended that they be field tested. KSU field tested several patterns of rumble strips, i.e., varying width and spacing. After selecting the best patterns, KDOT installed about 15 miles of two patterns of on the centerline of a two-lane state highway.

Concurrently, the authors were contractors on an NCHRP synthesis on U.S. and Canadian experience with CLRS. This K-TRAN report summarizes the findings of safety benefits and non-benefits from this nationwide survey. It describes research on the Kansas test patterns leading to recommendations on the best patterns, and the results and conclusions of field testing of these patterns regarding drivers' acceptance and perceived benefits of CLRS. The overall conclusion of this study is that the safety benefits of CLRS outweigh some non-benefits and they are a viable, low-cost safety device for reducing cross over crashes on two-lane highways.

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REDUCING CROSSOVER ACCIDENTS ON KANSAS HIGHWAYS USING MILLED CENTERLINE RUMBLE STRIPS

Final Report

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A Report on Research Sponsored By

THE KANSAS DEPARTMENT OF TRANSPORTATION
TOPEKA, KANSAS

and

KANSAS STATE UNIVERSITY
MANHATTAN, KANSAS

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PREFACE

The Kansas Department of Transportation's (KDOT) Kansas Transportation Research and New-Developments (K-TRAN) Research Program funded this research project. It is an ongoing, cooperative and comprehensive research program addressing transportation needs of the state of Kansas utilizing academic and research resources from KDOT, Kansas State University and the University of Kansas. Transportation professionals in KDOT and the universities jointly develop the projects included in the research program.

NOTICE

DISCLAIMER

ABSTRACT

In the USA, shoulder rumble strips are very common. It is estimated that they reduce run-of-the-road crashes up to 25%. KDOT has installed rumble strips on the shoulders of almost all state highways in the state. However, Kansas has several miles of two-lane highways with no shoulder. These highways have a number of single vehicle run-of-the-road crashes (both sides) as well as crashes from cars going across the centerline and colliding with on-coming vehicles (crossover crashes). Some U.S. states have been using or experimenting with centerline rumble strips (CLRS). In most states that use them, they are used only on no-passing sections or curves. KDOT contracted with Kansas State University (KSU) to survey other states and summarize their experience and to develop a research design to evaluate KDOT test installations. KSU surveyed U.S. and Canadian provinces and found no serious negative problems with CLRS and recommended that they be field tested. KSU field tested several patterns of rumble strips, i.e., varying width and spacing. After selecting the best patterns, KDOT installed about 15 miles of two different patterns on the centerline of a two-lane state highway.

Concurrently, the authors were contractors on an NCHRP synthesis on U.S. and Canadian experience with CLRS. This K-TRAN report summarizes the findings of safety benefits and non-benefits from this nationwide survey. It describes research on the Kansas test patterns leading to recommendations on the best patterns, and the results and conclusions of field testing of these patterns regarding drivers' acceptance and perceived benefits of CLRS. The overall conclusion of this study is that the safety benefits of CLRS outweigh some non-benefits and they are a viable, low-cost safety device for reducing cross over crashes on two-lane highways.

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CHAPTER 1

Centerline Rumble Strips

1.1 Background

Rumble strips have been in use since 1954, when they were first developed by the Illinois Highway Department to warn drivers they were approaching a stop sign at rural intersections (Gupta, 1994). Rumble strips of a raised or grooved pattern of specific dimensions are placed on the roadway surface or shoulder at specific intervals to “warn drivers of the need to stop, slow down, or change lanes” (Harwood, 1995). They are also used to indicate “changes in roadway alignment,” indicate that the vehicle has “partially or completely left the travel lane,” and to alert the driver of “other potentially unexpected situations” (Harwood, 1993). These rumble strips produce an “audible and tactile warning” to the driver (Harwood, 1993). These warnings are intended to alert inattentive or drowsy drivers that they are drifting out of their lane. Shoulder rumble strips are common in the United States (U.S.) to reduce run off the road (ROR) crashes. In recent years, some states started using Centerline Rumble Strips (CLRS) in an attempt to reduce crashes on two-lane roads from drivers crossing the center line and colliding with on-coming vehicles in the left lane.

CHAPTER 2

Kansas CLRS Study

The Kansas Department of Transportation (KDOT) was considering the installation of centerline rumble strips (CLRS) in 1999 and sponsored a study, which had three parts:

1. A brief literature review and survey to get some information on the effectiveness and to be sure there were no known negative aspects,
2. An analysis of the optimal dimensions and pattern, and
3. A field test of the most effective pattern(s).

CHAPTER 3

Rumble Strips Literature Review and Survey: 1999

In the fall of 1999, Kansas State University (KSU) researchers sent an e-mail survey to the Departments of Transportation (DOTs) in each of the 50 states and the Canadian provinces. This survey was written to address the following questions:

- Are centerline rumble strips in use?
- How were they constructed (milled or rolled)?
- What are their dimensions? (width, length, depth)
- What pattern type was chosen?
- Are they located in all zones or only in double yellow ‘no passing’ zones?
- How long have they been in use?
- Has any data been gathered?
- What type of research was conducted on that data?
- What where the results?

Twenty-four replies were received to this e-mail survey, a response rate of 40 %. Nine respondents – Pennsylvania, California, Oregon, Arizona, Massachusetts, Washington, Connecticut, Colorado and the Canadian province of Alberta – indicated they had centerline rumble strips installed.

A phone survey was conducted in the fall of 1999 of the States’ DOTs with centerline rumble strips in place. The Canadian province of Alberta was also contacted. The main purpose of the survey and phone contacts was to accumulate and analyze data regarding the types and dimensions of centerline rumble strips being installed in these locations and any problems or concerns that arose. California, Oregon, Massachusetts, Washington, Arizona, Colorado, Connecticut, Pennsylvania, and Alberta, Canada, had centerline rumble strips installed at various locations and provided the information sought by the KSU researchers. This information can be seen in Table 3.1.

Table 3.1: Various Other States' Milled Centerline Rumble Strips
(Rys et al., 2003)

State	Width	Length	Depth	Center	All Zones or No Pass Only	Comments
California	6.5"	16"	0.5"	Continuous 24"	No Pass Only	Used with raised thermoplastic striping and reflectors
Washington	6.5"	16"	0.5"	Continuous 12"	No Pass Only	Markings installed over strips
	6.5"	16"	0.5"	Continuous 24"	No Pass Only	Markings installed over strips
Oregon	7"	16"	0.63"	Continuous 12"	No Pass Only	Used with 4' median
Arizona	6.5"	12"	0.5"	Continuous 12"	All Zones	Markings installed over strips
	6.5"	8"	0.5"	Continuous 12"	All Zones	Narrower to reduce residential noise
	6.5"	5"	0.5"	Continuous 12"	All Zones	Narrower to reduce residential noise
Massachusetts	6.5"	18"	0.5"	Continuous 12"	No Pass Only	Markings installed over strips
Pennsylvania	6.5"	30"	0.5"	Alternating 24 & 48"	No Pass Only	Across centerlines - 12' lanes
	6.5"	16" each	0.5"	Alternating 24 & 48"	No Pass Only	Outside centerlines - 12' lanes
	6.5"	16"	0.5"	Alternating 24 & 48"	No Pass Only	Between centerlines - 12' lanes
	6.5"	18"	0.5"	Alternating 24 & 48"	No Pass Only	Across centerlines - 11' lanes
	6.5"	10" each	0.5"	Alternating 24 & 48"	No Pass Only	Outside centerlines - 11' lanes
	6.5"	12"	0.5"	Alternating 24 & 48"	No Pass Only	Between centerlines - 11' lanes
Colorado	6.5"	12"	0.5"	Continuous 12"	All Zones	Markings installed over strips
Connecticut	6.5"	16"	0.5"	Continuous 12"	No Pass Only	Markings installed over strips
Alberta, Canada	6.5"	12"	0.5"	Continuous 12"	No Pass Only	Markings installed over strips

Note:
Width - represents dimension parallel to travel surface
Length - represents dimension perpendicular to travel surface
Depth – represents dimension downward (cut) from the top of the surface
Center - spacing between center of strips

During the 1999 phone survey, contacts in all states in Table 3.1 were interviewed. Several positive comments and no negative comments were received. Examples of the positive comments follow (Russell, et al., 2000).

One Colorado District Traffic Engineer said she was initially "skeptical" of the value of CLRS. The roadway with CLRS in her district is a hilly winding, two-lane road with a high percentage of slower RVs. She is convinced from observation that the continuous (both passing and no passing zones) CLRS has cut down much “high risk” passing and the “peeking out” maneuver where drivers move into the left lane to see what is coming (Hutton, 2000).

Probably the strongest advocate interviewed at this time was an Arizona District Engineer. He stated that he would put continuous CLRS on all two-lane roads in the district if the money were available. He added that he felt they should be continuous and not just on curves or in no-passing zones. He reasoned that drivers are more likely to go to sleep on long straight stretches (Dorman, 2000).

The California (CALTRANS) representative provided before and after data for their “Raised Profile Thermoplastic Stripe/Rumble Strip in San Louis Obispo County.” The 22.8 mile stretch had 126 crashes with 13 fatalities before and 112 crashes with 3 fatalities and 44 injuries after installation – a 71 % reduction in fatalities (Nunn, 2000).

Good positive results in Oregon were also reported. On a mountain road to a ski resort, fatalities dropped from nine (the year before) to zero. It was noted that the section was designated as a safety corridor and had other safety treatments. However, it was stated that Oregon DOT personnel feel very positive about CLRS (Sciscrone, 2000).

The Washington interviewee reported they had no data but the perception is that their system has been very effective. He believes drivers do not pass as often and are more apt to drive at the speed limit (Walsh, 2000).

In Alberta Canada, it was reported that they were proceeding cautiously and had no data after two years. Although no data was available, he believed CLRS to be effective and there were no problems or negative concerns (Kenny, Alberta Canada Highway Department).

The overall conclusion from the 1999 telephone survey was that all persons contacted were slightly to very positive about CLRS and no negative problems were uncovered. The KSU researchers recommended that KDOT proceed with a field demonstration.

After compiling and analyzing the results of the survey, it became apparent that there were no standards for the types and dimensions of rumble strips being used and tested. A proposal was drafted for centerline rumble strip testing. This proposal called for the evaluation of three different patterns (continuous 12 inches on center, continuous 24 inches on center, and alternating 12 & 24 inches on center) consisting of four different widths each (5, 8, 12, and 16 inches), for a total of 12 test patterns. Decibel (dB) and steering wheel vibration (g) levels would then be recorded at the driver's position during a series of tests at various speeds utilizing multiple vehicle types. This testing would attempt to validate an optimum pattern for centerline rumble strip installations in the state of Kansas.

CHAPTER 4

Updated Centerline Rumble Strips (CLRS) Literature Review and Survey: 2002

In 2002, the authors conducted a comprehensive literature review and 50-state survey as consultants on an NCHRP Synthesis project. The following are the key findings (Russell and Rys, 2004).

4.1 Summary (Under Review by NCHRP)

The primary purpose of centerline rumble strips (CLRS) is to warn drivers whose vehicles are crossing centerlines of two-lane, two-way roadways to avoid potential crashes with opposing traffic. Two types of crashes are generally considered correctable by CLRS: head-on and opposite direction sideswipes often referred to as cross-over or cross centerline crashes. The consultants believe that a definition proposed by the state of Missouri should be adopted: “Crashes that qualify as CLRS correctable are any cross- centerline (cross-over) crash that begins with a vehicle encroaching on the opposing lane, excluding any crash that began by running off the road to the right and overcorrecting and any crash that began by a vehicle going out of control due to water, ice, snow, etc., prior to crossing the centerline” (Zieba, 2004).

The use of centerline rumble strips (CLRS) has been growing since around 1999. Early surveys in 2000 indicated that 20 states and one Canadian province with CLRS appeared to have experimental sections of a few miles and the maximum reported treatment was 15 miles. In the current survey 22 states and two Canadian Provinces reported they had CLRS, an increase of only two states and one Canadian province; however, the number of lane miles of CLRS has greatly increased, with one state reporting 300 miles. In regard to where they were used, 14 respondents answered they were used continuously, four answered they were used only on no passing sections, two answered they were used only on curves and two answered they were used only on specific sections. Two did not respond. It appears that at least the majority of the 22 states reporting their use believe they are an effective safety counter measure to head-on and opposite direction sideswipe, cross-over crashes. Six states reported no interest in using CLRS. There are indications in survey answers that other states are waiting for more positive evidence before installing CLRS. CLRS are clearly still in the experimental stage.

In the United States, crashes on rural roads account for 60 % of all fatal crashes. Approximately 90 % of these fatal crashes occur on two-lane roads. Vehicles crossing the centerline of two-lane roads and either sideswiping or striking opposing vehicles head on account for 20 % of all fatal crashes on these two-lane roads and result in approximately 4,500 annual fatalities (Persaud et al., 2003).

CLRS primarily address the problem of drowsy or inattentive drivers on two-lane, two-way highways drifting left out of their lane and striking an oncoming vehicle. The most compelling evidence supporting CLRS use is the reduced crashes and lives saved. A report by Delaware that calculated a Benefit/Cost ratio of 110 to 1 is impressive albeit it is based on a 2.9 mile section and short before and after periods. Several other states reported significant reduction in overall crashes, and/or fatal crashes. A few states reported the data showed no significant decrease in crashes after the installation of CLRS. Most before and after studies are based on very few years of data.

The most reliable evidence of the value of CLRS is a recent study conducted by the Insurance Institute of Highway Safety (IIHS). In this study the researchers collected and analyzed all data in the United States that they considered reliable, and using the Empirical

Bayes method and data from seven states with 210 miles of CLRS, concluded overall motor vehicle crashes at sites treated with centerline rumble strips were reduced 14 %. Injury crashes were reduced by an estimated 15 %. Frontal and opposing-direction sideswipe crashes were reduced by an estimated 21 %. Front and opposing-direction sideswipe crashes involving injuries were reduced by an estimated 25 %. When the crashes were disaggregated into nighttime and daytime crashes, the percent reduction at night was greater than during the day – 19 % vs. 9 % – but the difference was not statistically significant at the 5 % level (p = 0.096). Data on fatalities was insufficient to draw any conclusions (Persaud et al., 2003).

Information currently available and the IIHS study leads to the conclusion that installing CLRS reduces cross-over crashes. However, confidence in the quantitative nature of most before and after analysis is limited by the fact that most CLRS installation have been in place a short time, and more than one or two years of after data would be desirable. In regard to analyzing crash data, some guidelines or standardization should be developed. It is essential that "regression to the mean" be considered. It is difficult to quantitatively compare results analyzed for different time periods and/or by different methods. States with the CLRS sites in place should continue monitoring and analyzing the data.

Although the overall conclusion from the currently available materials is that CLRS are a low-cost, effective countermeasure for mitigating cross-over crashes on two-lane roadways, there are some concerns. The two most often concerns reported in the survey are external noise and reduced visibility of the centerline striping material (generally paint). However, some respondents commented that the painted stripes over CLRS are more visible during rain. Pavement deterioration, ice buildup in the groves, and adverse impact on emergency vehicles were also reported as concerns; however, these were isolated concerns with each being expressed by only one or two states. Concerns regarding bicyclists' safety are potentially more serious. Three states indicated negative comments from the bicycling community (Colorado, Wyoming and Pennsylvania). The stated concern of bicyclists was that when CLRS are present, motorists do not move over toward or cross the centerline to provide sufficient space when passing bicyclists. This safety concern is given credibility by Penn State University research results that showed motorists shift their position in the lane away from the centerline in the presence of CLRS, albeit no bicycles were present in the study. Colorado research noted that "there could be an increased danger to bicyclists"

http://bicyclecolo.org/site/page.cfm?pageID=281

[December 6, 2002]

One innovative design was uncovered to address the reduced visibility of centerline striping and potential damage to the centerline joint. Minnesota developed a section for areas with double 4-inch strips (no-passing zones) that has 6-inch (lateral dimension) rumble strips 2-inches outside of the stripes on each side (Figure 4.1). The objective is to reduce problems with the visibility of the stripes and possible deterioration of the centerline joint.

Most of the states using CLRS have installed milled CLRS. The length (perpendicular to the centerline) of the CLRS varies from 12- to 30-inch with 12- and 16-inch being used predominantly. The width (along the centerline) varies from 4- to 8-inch with 7-inches used predominantly. Depth of the groves is commonly ½-inch. The definition of width as the dimension along the centerline and the length as the dimension perpendicular to the centerline is used by most states and throughout this report. (It was noted that several states with CLRS call width the dimension perpendicular to the centerline and length the dimension along the centerline.) Either the continuous or alternating patterns proposed by Kansans' researchers are adequate to create the tactile and auditory response to alert drivers crossing over the centerline. Most of the states did not have to adjust the width of the road because of the CLRS installations. The reduction in a drivable area did not create problems in the majority of the states.

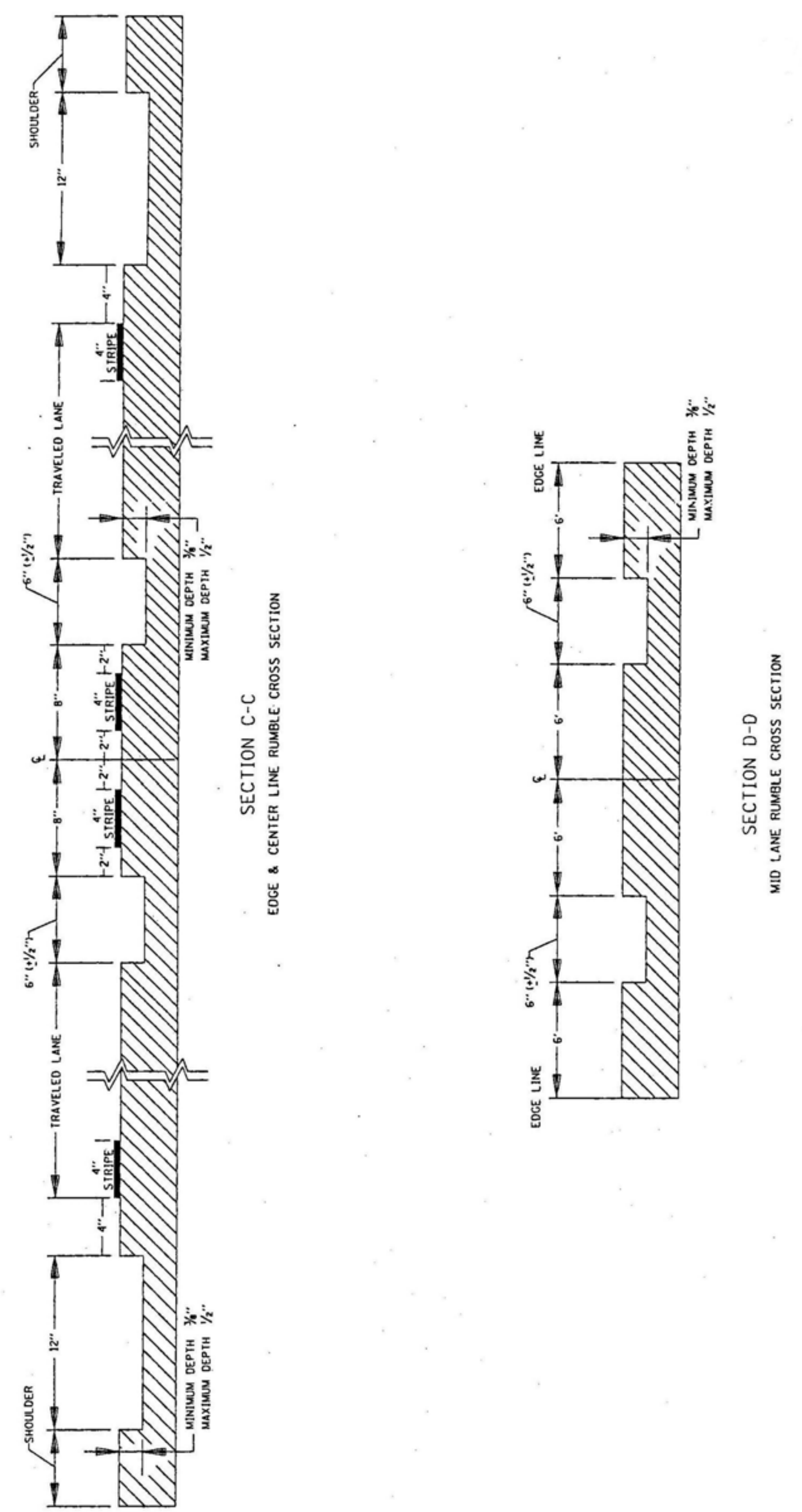

Figure 4.1: Redesigned Minnesota DOT Centerline Rumble Strips
(Cook Research and Consulting, Inc., 2001)

Few states reported having a policy for installation of centerline rumble strips. California, Oregon, Pennsylvania and Utah are the four states that responded initially and sent policies or guidelines. A few other states responded with drawings of installations e.g., Kentucky, Kansas, Minnesota. The province of Alberta also sent drawings. Later, as the result of a supplementary survey, Minnesota sent draft guidelines and Missouri sent draft warrants. All of this material is presented in the NCHRP synthesis and/or appendices (Russell and Rys, 2004). Overall, beyond this material mentioned above, there are no standard policies, guidelines, or warrants on the design and use of CLRS.

An attempt was made to determine if CLRS were used internationally. This was done by literature search and personal contacts in England, Europe and Australia. There was no indication of any use of CLRS outside of the United States and Canada.

4.2 Key Issues (Under Review by NCHRP)

4.2.1 CLRS Effectiveness

Most information on CLRS obtained from published and unpublished literature, a nationwide survey and personal contacts was positive and the available "body of evidence" suggests they reduce cross-over crashes on two-lane roadways and save lives. There are some negative aspects, but the positive aspects appear to far outweigh the negative ones. Analysis should continue and more studies should be conducted to address the negative points, such as centerline marking visibility, pavement deterioration, effects on motorcycles and risk to bicyclists, particularly on roadways with narrow or no shoulder.

4.2.2 Extent of CLRS Use

Based on two recent surveys – in 2000 (by Noyes and Elango) and 2003 (by Russell and Rys) – during that period the number of states with CLRS only increased from 20 to 22, and the number of Canadian provinces from one to two. However the number of miles of CLRS increased considerably. In 2000, the maximum miles in any state of CLRS were 15. In 2003, there was one state with 300 miles and the total miles of all states using CLRS increased significantly to over 2000. Several states reported having only a few miles in 2003, indicating they still tend to be experimental. Six states indicated they have no interest in CLRS. Most states that have not installed or have not considered using them appear to be waiting for more "evidence."

4.2.3 Compilation of Positive Findings

- Several states using CLRS reported reduction in overall crashes, targeted (cross-over) crashes, injury crashes and/or fatal crashes.
- A report setting forth guidance for implementation of the AASHTO strategic safety plan cited positive reviews of CLRS reducing crashes in three states and found no significant negative effects. (Neuman, T.R., et al, 2003)
- A Pennsylvania study reported that PENNDOT felt that the safety effectiveness of CLRS was well documented (Mahoney, et al., 2003).
- A Delaware study on 2.9 miles of CLRS reported a benefit/cost ration of 110
- (**www.deldot.net/static/projects/rumblestripindex.html** November 2003).
- The overall conclusion of comprehensive three-phase study conducted in Massachusetts was that CLRS are a recommended countermeasure in areas where cross-over crashes occur (Noyce and Elango, 2003).
- Although the quality of the statistical analysis used in the studies above that report crash reductions is unknown in most cases, a comprehensive study using reliable data available from seven states and state-of-the-art statistical methodology found that overall vehicle crashes were reduced by an estimated 15 %, injury crashes were reduced by an estimated 15 %, head-on and opposing direction crashes were reduced by an estimated 21 %, head-on and opposing direction sideswipe crashes involving injury were reduced by an estimated 25 % (available data were

insufficient to make any conclusions about reductions in fatal crashes) (Persaud, et al., 2003).

- Ninety-six percent of respondents to the KSU study of Kansas drivers felt that installation of centerline rumble stripes would reduce crashes. Minnesota also reported driver satisfaction with CLRS.
- Benefits beyond safety were also reported by some states; e.g., knowing where the centerline is in conditions of poor visibility like blowing snow. (Cook Research and Consulting, June 2001)

4.2.4 Compilation of Negative Findings

No "reliable evidence" of negative effects was uncovered; however there are several concerns that have not yet been proven, unproven or, in some cases, adequately studied:

- Danger to bicyclists,
- Effect on motorcycles,
- Roadside noise complaints,
- Drivers reacting to the left,
- Pavement deterioration,
- Effect(s) on different types of pavement material,
- Striping visibility,
- Snowplow increased wear,
- Limited after data,
- Effect(s) on emergency vehicles,
- Lack of widely accepted guidelines, and
- Water, snow and ice accumulation.

4.2.5 Specific Key Issues in NCHRP Synthesis Scope

In conducting the NCHRP Synthesis, Russell and Rys (2004) addressed several specific topics: warrants, design, operational effects, effects on crashes, impacts on bicyclists, maintenance, cost and other issues. The following summarizes their findings categorized by these specific topics listed in the synthesis final scope.

Warrants: No warrants were uncovered in the review of literature, original survey or personal contacts. Five states sent policy or guidelines (California, Oregon, Pennsylvania, Utah and Minnesota). These are presented in Appendix C of the draft NCHRP synthesis. To be sure nothing was missed, a supplementary survey specifically addressing warrants was emailed to all 54 persons who had responded to the original NCHRP survey. Although there were only 18 replies, these replies represented the majority (14/24 or 58%) of the states and provinces that have CLRS. Thirteen of the 18 respondents answered that warrants were not appropriate for CLRS. Those not in favor of warrants generally favored using "engineering judgment" for specific sections. Two answered "yes" and one, Missouri, sent draft warrants.

Commonalities found in draft policies, guidelines and the one draft warrant are as follows:

- Roadway type: Rural two or three-lane undivided
- Crash History: All documents address numbers of crashes or crash rates and indicated CLRS should be used on sections where some number (unspecified) of cross-over crashes have occurred. Only California policy contains a specific, weighed average number based on a value for various levels of five categories: number of total crashes, number of deaths, fatal accident rate, death rate and total accidents per mile. The five categories are summed and a value of 40 (plus a cross-over fatality during 1998) triggers an investigation of the site.
- Speed: 50 mph or greater
- ADT Threshold: 1500 to 3500
- Lane width: No less than 10', with 11' or 12' more common
- Pavement type: Primarily asphalt in good condition with minimum depths of 2.5" to 2.75"
- Noise: Consider noise

- Coordination: Coordinate with all other project tasks and install CLRS last

Design: There is no standard design. Current designs by all 54 states and provinces responding to the survey are detailed in the draft NCHRP synthesis. (Russell and Rys, 2004) The most common types are milled, 12” to 16” long (perpendicular to the centerline), 7” wide (along the centerline), ½” deep, with the two most common patterns being a “continuous” 12” to 24” apart or “alternating” with pairs of rumble strips being 12” or 24” apart with the pairs being 24” or 48” apart, respectively. The Kansas study by KSU is the only one that reported research on vibration and noise and concluded that either the 12” continuous or alternating pairs 12” apart with the pairs 24” apart, provided the optimum, required response to alert drivers. Oregon has a unique section in a 4-foot median with the painted strips outside of the rumble strips. (Mousere, C.M., 2002) Minnesota has a unique section with the rumble strips outside of the painted centerline stripes. (Figure 4.1)

Operational Effects: The main question regarding operational effects is whether drivers are so conditioned to right-side, shoulder rumble strips that they will “jerk” the wheel to the left when encountering CLRS. The NCHRP consultants found no clear evidence that this potentially dangerous action would occur. One Massachusetts simulator study found that 27 percent of subjects did steer to the left. (Noyce and Elango, 2003) The researchers of the Massachusetts study concluded that although the result could have been due to conditions inherent in simulator studies, the possibility exists and should be further studied. It should be noted that in this study the subjects were first exposed to right shoulder rumble strips and CLRS. No left shoulder rumble strips, which the consultants believe are now as common as right shoulder rumble strips, were introduced in the study. Also, in the study the vibration was transmitted through the vehicles’ seat whereas in reality, vibration is transmitted through the steering wheel.

Other operational issues uncovered by the consultants involve lane placement, speed, level of service and weather conditions. There was one Pennsylvania study that found that there was a movement of vehicles away from the CLRS on the order of several inches. (Mahoney, K.M. et al, 2003) This movement would increase the separation of opposing vehicles and potentially increase safety. A potential negative effect would be on routes where there are bicyclists. Bicyclists claim vehicles on roads with CLRS, hesitate moving left and create a potentially dangerous situation for them. Bicyclists are particularly concerned on winding roads and roads with no shoulder. (Bicycle Colorado, 2002) This effect needs more study and certainly should be considered in any decision to use CLRS.

No studies or information were uncovered regarding the effects on speed or level of service.

In regard to weather conditions, the little information uncovered was positive. Focus groups in Minnesota indicated that CLRS were helpful in identifying the roadway center line during adverse weather like blowing snow. Only one instance of water or ice being a problem was uncovered and this was on an Alaskan highway section that never was exposed to sun. (Adler, C., 2001)

<u>Effects on Crashes:</u> The body of evidence uncovered leads to the conclusion that CLRS are an acceptable countermeasure to reduce cross-over crashes, injuries and fatalities. Crashes are in reality a rare occurrence and for a given roadway segment several years of data or several combined data bases are generally required in order to apply sophisticated statistical techniques that produce “statistically significant” results that most accept as “evidence” that some treatment resulted in an effect caused by the treatment and not by chance. In the case of CLRS, the effect

of interest is considered evidence that CLRS had a positive effect, i.e., reduced cross-over crashes.

Several states reported decreases in cross-over crashes due to the installation of CLRS. Most did not claim statistically significant results, and with two exceptions, information available to the consultants was insufficient to determine the quality of the data or the statistical methodology. It should be noted that lack of a statistically significant result does not always mean there is none; it could be because data is insufficient to show one. It is possible that some results are inflated; however in all cases uncovered the trends were positive. In all cases, the trends showed decreased cross-over crashes. These trends and the IIHS study (Persaud, et al., 2003), in which statistical experts used state-of-the-art statistical techniques and combined data from seven states, and concluded that there were statistically significant reductions in all cross-over crashes and injury crashes due to CLRS installation, support the conclusion that CLRS are effective in reducing CLRS crashes.

<u>Impacts on Bicyclists:</u> The most negative information uncovered in this regard was from Colorado. Bicyclists and Bicycle organizations in Colorado actively oppose CLRS, particularly on winding mountain roads and roads with no shoulder. This issue needs to be considered and studied further. Two other states, Wyoming and Pennsylvania, mentioned concerns.

<u>Maintenance:</u> Although no clear evidence was uncovered, there is definitely the possibility that CLRS milled over the centerline could increase or accelerate the typical centerline pavement joint. Minnesota uses unique section with the rumble strips milled outside of the centerline strips. Long-term research is needed. As a minimum, CLRS should be installed only in good pavement. In Minnesota, maintenance personnel have brought up issues related to

additional wear on snow removal equipment. This issue needs to be addressed by individual states.

Cost: It is very difficult to get good, accurate cost data. This fact appears to be due to the fact that CLRS are not usually installed alone but as the final operation in a series of improvements to a roadway section. The consultants consider the estimate of Dustrol Inc. of Towanda, Kansas to be a reliable one because Dustrol only does CLRS installation. The $0.26 to $0.85 per linear meter appears reasonable at this time.

Other Issues:

- Motorcycles – nothing beyond limited anecdotal information was uncovered. This information indicated CLRS were not a problem with motorcyclists.
- Centerline Strip Visibility - This is an indeterminant issue. Information is anecdotal and as many persons who say centerline visibility is decreased when placed over CLRS; as many more say visibility is enhanced. There is subjective agreement that CLRS enhance centerline strip visibility in wet weather and rainy conditions. One opinion expressed to the consultants was that paint sprayers placing paint over CLRS tend to put a heavier coat on one side of the milled rumble strip. This condition may make them more visible in one direction than the other and should be investigated.
- Noise - External noise toward roadsides and its effect on roadside residences should be considered. Many responses noted it should be "considered" but no definite numbers were presented except in a Transportation Association of Canada (TAC) report that states CLRS terminated 200 meters prior to residential or urban areas produce tolerable noise impacts on residents, and at 500 meters the noise is negligible (TAC Synthesis, 2000).

4.3 Conclusions (Under Review by NCHRP)

The following are conclusions that Russell and Rys (2004) arrived at regarding the main issues uncovered while developing the NCHRP synthesis:

- CLRS are an effective safety countermeasure for reducing overall and injury cross-over crashes on two-lane, two-way roadways.
- States and Provinces with CLRS should continue to monitor the sections and expand their safety data base after CLRS installation.
- State-of-the-art statistical analysis procedures should be studied, promoted and used on the before and after analysis of CLRS sections.
- No conclusive evidence of negative effect of CLRS were found; however several concerns or potential negative effects have yet to be proven or disproven, particularly the safety effect on bicyclists, and need additional study.
- Warrants - in the context of MUTCD type warrants for highway signing – are not appropriate for CLRS; guidelines are preferred.
- For consistency within a state or agency, CLRS guidelines should be developed based on engineering judgment considering such things as traffic volume (ADT), numbers and/or rates of cross-over crashes, roadway type, geometry and location, regional conditions and experience.

CHAPTER 5

Kansas CLRS Pattern Tests

For the test purposes, the rumble strips were installed in such a way that the general driving public would not contact them under normal driving circumstances.

The Kansas centerline rumble strip test patterns were installed in May 2000 by Dustrol Inc. of Towanda, Kansas, on the southbound shoulder of Interstate 135 approximately eight miles south of Salina, Kansas. See Figure 5.1 for a picture of the milling operation for the Kansas tests.

The 12 test pattern sections were arranged as follows:

- Section 01: Continuous 12 inches on center / 16 inches long
- Section 02: Continuous 24 inches on center / 16 inches long
- Section 03: Continuous 12 & 24 inches on center / 16 inches long
- Section 04: Continuous 12 inches on center / 12 inches long
- Section 05: Continuous 24 inches on center / 12 inches long
- Section 06: Alternating 12 & 24 inches on center / 12 inches long
- Section 07: Continuous 12 inches on center / 8 inches long
- Section 08: Continuous 24 inches on center / 8 inches long
- Section 09: Alternating 12 & 24 inches on center / 8 inches long
- Section 10: Continuous 12 inches on center / 5 inches long
- Section 11: Continuous 24 inches on center / 5 inches long
- Section 12: Alternating 12 & 24 inches on center / 5 inches long

The cutting spindle on the milling machine used had a 12-inch milling radius and the depth of cut was 0.5 inch on all patterns.

The test patterns were constructed on the right shoulder of an interstate highway (I-135). KDOT erected a highway work zone that blocked the traffic lane adjacent to the test strips, so that highway traffic would not become a factor in the testing and to help ensure the safety of the drivers of the test vehicles which traveled against the normal flow of traffic with their left wheels in contact with the test patterns.

Figure 5.1: Dustrol Inc. Milling Machine
(Brin, 2001)

The vehicle tests were conducted using seven vehicles, which represent a wide spectrum of the vehicles currently in operation on Kansas highways. The seven vehicles consisted of: two large trucks (a 1996 International Harvester 4900 DT 466 dump truck and a 1995 Ford L8000 dump truck), a full-size pick up 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 vehicles negotiated the rumble strips in such a manner that the driver's left wheels made contact with the rumble strips.

Testing at this site consisted of both interior noise level testing near the drivers' ear and steering wheel vibration testing.

Interior noise level testing was conducted by measuring the noise levels generated by the rumble strips as the vehicles passed over each test section. The data was recorded using a Quest Technologies Model Q-300 dosimeter, with a remote microphone clipped to the driver's collar just below the right ear. This meter operates at 32 samples per second, and displays the high decibel reading taken during any one-second period. This data was entered into Microsoft Excel for evaluation. Each vehicle negotiated the rumble strips at 60 mph, because it is the current speed limit on many of the rural two-lane highways in Kansas.

The decibel level average for each of the seven test vehicles over each of the 12 test sections at speed of 60 mph (96.6 km/h) was calculated. Although there were many inconsistencies in the data, as can be seen in Table 5.1, the continuous 12-inch on center patterns produced the highest average decibel levels of 80 dB to 94 dB at 60 mph, depending on vehicle type (patterns P1, P4, P7 and P10), followed by the alternating 12 and 24-inch on center patterns (patterns P3, P6, P9 and P12). As for trends in decibel levels due to rumble strip length, it appeared that the longer rumble strips generally produced higher average decibel levels, but there was no consistency among the longer lengths. This could be explained as a result of the vehicle tires not remaining in full contact with the shorter rumble strip patterns, i.e., the shorter the pattern, the lower the probability of the vehicles' left tires making full contact with the pattern.

Table 5.1: Decibel Level Mean and Standard Deviation at Driver's Position – 60 mph
(Rys et al., 2003)

Vehicle	Pattern Tested											
	P12	P11	P10	P9	P8	P7	P6	P5	P4	P3	P2	P1
1996 IH 4900 DT 466	---	---	92.24	92.84	91.47	93.41	93.35	92.23	94.12	92.94	92.16	91.23
Dump Truck (GW=75,000)	---	---	0.852	0.490	0.482	0.546	0.346	0.494	0.429	0.373	0.685	0.316
1995 Ford L8000	---	88.21	92.31	90.54	90.03	92.01	91.43	90.48	92.73	91.07	90.73	91.34
Dump Truck (GW=48,000)	---	0.445	0.950	0.283	0.433	0.456	0.592	0.440	0.465	0.587	0.263	0.915
1991 Chevrolet 2500	---	---	85.29	84.11	81.44	88.77	84.18	82.68	87.47	83.77	82.86	83.50
Pickup Truck	---	---	1.117	0.753	0.614	1.242	0.896	0.572	0.796	0.452	0.845	1.194
1993 Pontiac Bonneville	82.86	79.01	83.32	83.75	79.46	83.59	84.65	79.61	84.24	83.48	80.01	82.89
Full-Size Passenger Car	1.053	0.703	0.786	0.459	0.371	0.970	0.374	0.150	0.274	0.179	0.312	0.568
1994 Ford Escort Wagon	---	85.60	88.42	88.62	87.75	89.74	87.44	86.57	89.97	87.76	86.22	87.34
Compact Passenger Car	---	0.390	0.990	0.083	0.465	0.483	0.238	0.083	0.430	0.508	0.351	0.711
1995 Ford Aerostar	82.56	80.62	87.83	84.09	82.83	89.49	86.12	84.97	87.77	85.59	85.89	88.33
Minivan	1.255	1.083	0.437	0.604	0.851	0.692	0.668	0.530	0.600	0.612	0.904	1.146
1997 Jeep Cherokee	---	---	---	82.82	79.87	86.76	84.22	80.48	88.65	83.80	81.24	85.63
SUV	---	---	---	0.563	0.725	0.683	1.014	0.419	0.338	0.544	0.821	0.676
GRAND MEAN	**82.71**	**83.36**	**88.24**	**86.68**	**84.69**	**89.11**	**87.34**	**85.29**	**89.28**	**86.92**	**85.59**	**87.18**

Note:
--- Indicates that the test results were inconclusive
For each vehicle the first row of numbers is the mean and the second row is the standard deviation.
P12 = Section 12………P1 = Section 01

Steering wheel vibration testing was conducted by measuring the vibration levels in the steering wheel of each vehicle that was generated by the rumble strips as the vehicle's left wheels pass over each test section at 60 mph. The data was recorded using a MicroDAQ Model of SA-600 accelerometer, which was firmly attached to the steering wheel of the vehicle by duct tape. During testing, the drivers were instructed to maintain as minimal contact with the steering wheel as safely possible, so that the dampening effects caused by touching the steering wheel would be minimized.

Although there was considerable variation in the data, the alternating 12- and 24-inch on center pattern produced the highest average vibration levels in four of the six vehicles and the second highest average levels in the other two. Conversely, the continuous 24-inch on center pattern had none of the highest vibration levels, and only produced the second highest in two of the six. Thus, the highest overall vibration was produced by the alternating 12- and 24-inch on center pattern, followed by the continuous 12-inch on center pattern, and lowest were produced by the continuous 24-inch on center pattern (Table 5.2).

Based on the above tests, it was decided to field test both pattern 4 (12 inches long, continuous 12-inch on center) and pattern 6 (12 inches long, alternating 12-inch and 24-inch on center). The 12-inch rumble strip length was determined subjectively. Length made little difference in the decibel and vibration values and 12-inch length fit the centerline striping best, i.e., 12 inches between the outside edges of 4-inch, double yellow centerlines spaced 4 inches apart.

Table 5.2: Steering Wheel Vibration G-Forces Mean and Standard Deviation – 60 mph

Vehicle	Pattern Tested								
	P9	P8	P7	P6	P5	P4	P3	P2	P1
1996 IH 4900 DT 466 Dump Truck (GW=75,000)	--- ---	--- ---	--- ---	--- ---	--- ---	--- ---	--- ---	--- ---	--- ---
1995 Ford L8000 Dump Truck (GW=48,000)	1.44 0.178	1.24 0.146	1.30 0.194	1.56 0.167	1.14 0.149	1.31 0.197	1.46 0.198	1.23 0.149	1.35 0.232
1991 Chevrolet 2500 Pickup Truck	1.42 0.372	1.09 0.093	1.93 0.402	1.51 0.245	1.26 0.141	2.05 0.255	1.68 0.293	1.38 0.204	1.69 0.459
1993 Pontiac Bonneville Full-Size Passenger Car	1.35 0.420	1.14 0.206	1.97 0.249	1.25 0.166	1.24 0.133	1.44 0.269	1.21 0.240	1.44 0.112	1.69 0.373
1994 Ford Escort Wagon Compact Passenger Car	1.47 0.139	1.06 0.145	1.14 0.139	1.25 0.186	1.32 0.129	1.19 0.154	1.45 0.203	1.33 0.106	1.34 0.138
1995 Ford Aerostar Minivan	1.42 0.353	1.37 0.201	1.52 0.327	1.68 0.184	1.34 0.191	1.47 0.223	1.69 0.272	1.43 0.220	1.59 0.310
1997 Jeep Cherokee SUV	1.64 0.265	1.34 0.183	1.49 0.302	2.31 0.229	1.85 0.391	1.93 0.185	2.33 0.364	1.60 0.322	1.73 0.396
GRAND MEAN	**1.46**	**1.21**	**1.56**	**1.59**	**1.36**	**1.57**	**1.64**	**1.40**	**1.57**

Note:
--- Indicates that the test results were inconclusive

For each vehicle the first row of numbers is the mean and the second row is the standard deviation.

5.1 Surface Considerations

KDOT indicated that milled rumble strips are equally well suited for installations on both asphalt and concrete roadway surfaces, with two possible exceptions. The first is when milling on asphalt, the thickness of the most recent (topmost) overlay should exceed the depth of the rumble strips, so that the integrity of the overlay seal with the next layer of asphalt is not compromised. The second is when milling on concrete, it is important to avoid milling over the roadway joints (Crow, 2001).

5.2 Installation Costs

Dustrol Inc. indicated that the cost of installing milled centerline rumble strips currently varies between $0.26 and $0.85 per linear meter (Dankert, 2001). The reason for this wide variability is that there are several factors that influence the overall installation cost. First, anything affecting the speed at which the rumble strips can be milled is a substantial cost factor. These factors include the dimensions of the pattern (longer strips and deeper cuts require more time to mill), as well as the complexity of the pattern being milled. The type of roadway surface is also a factor, as milling in concrete is generally more time consuming than in asphalt, and thus is costlier. Another factor is the volume of traffic at the installation site, which affects the amount of traffic control (devices or otherwise) that are needed, and could possibly lead to unexpected delays in the installation. Other factors include the overall size of the installation, and the travel costs getting the equipment and work crews to and from the installation sites. Finally, the flexibility in the timeframe during which the installation is to occur is a cost factor, as a premium is charged for installations that must occur on a rigid schedule versus at the convenience of the installer.

5.3 Conclusions: Kansas Pattern Study

Based on the results of the tests conducted, two patterns were chosen for further testing in an actual highway setting, pattern 4 (continuous 12 inches on center, 12 inches long) and pattern 6 (alternating 12- and 24-inches on center, 12 inches long). These two patterns and dimensions chosen for further study in the field are shown in Figures 5.1 and 5.2. Seven miles of each pattern were installed on Route 50 between Newton and Hutchinson, Kansas. An evaluation of drivers' response was conducted in the fall of 2003 and the results are described in the next section.

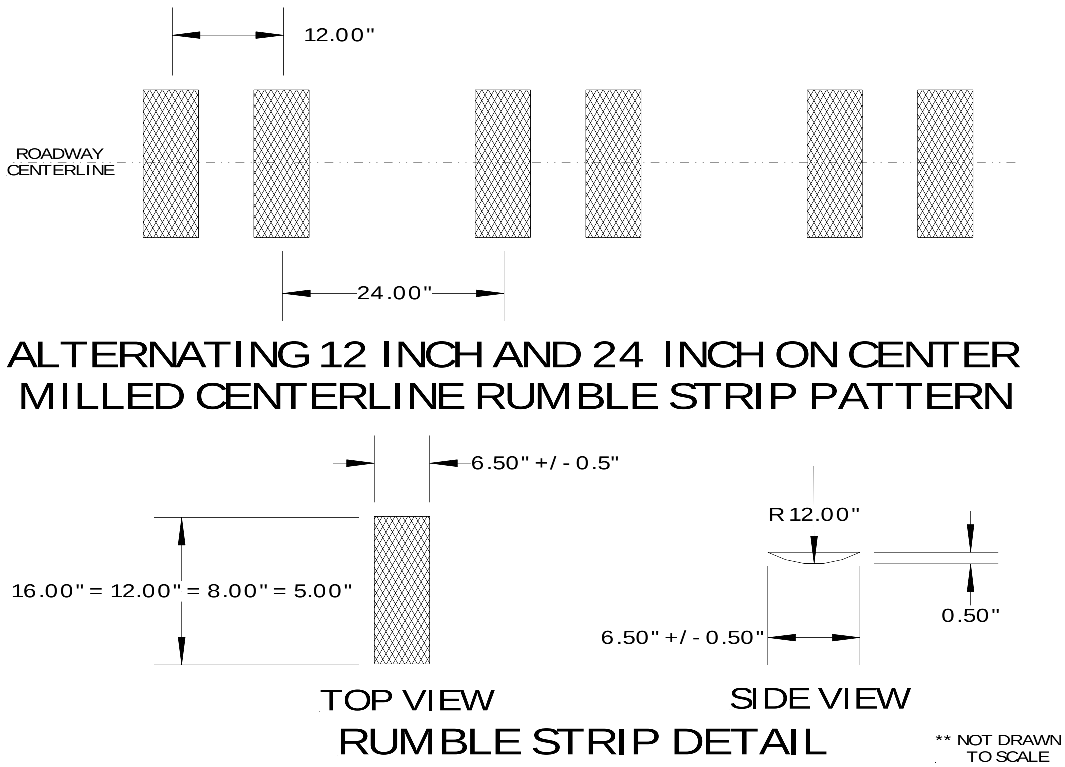

Figure 5.2: Kansas Blueprint of Alternating 12- and 24-inch on Center Pattern
(Brin, 2001)

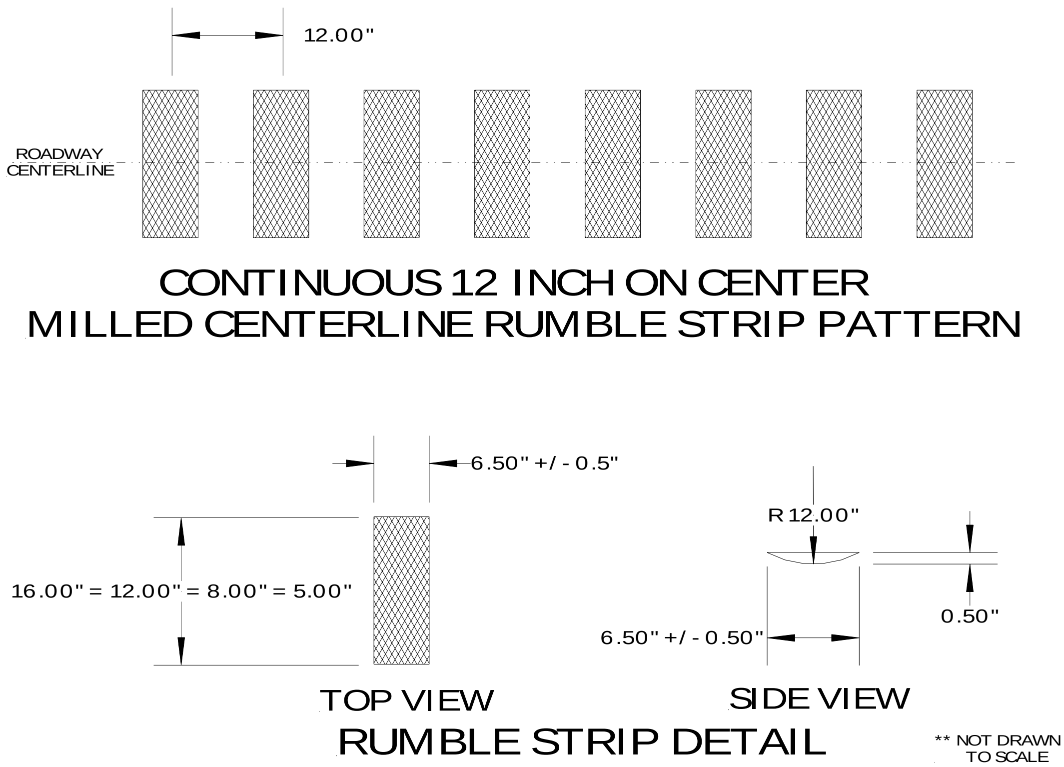

Figure 5.3: Kansas Blueprint of Continuous 12-inch on Center Pattern
(Brin, 2001)

CHAPTER 6

Kansas Driver's Responses to CLRS

The milled centerline rumble strips of two types – continuous 12-inch on center and alternating 12-inch and 24-inch (Figures 5.2 and 5.3) were installed on a 15-mile stretch of US-50, between the towns of Newton and Hutchinson in June 2003. The Kansas State University research team visited the site on November 25, 2003, to distribute survey questionnaires (see Appendix A) to the road users to find their response to the installation of the centerline rumble strips. The two-centerline rumble strip types have been marked with signs describing them as Test Section 1 (continuous 12-inch on center) and Test Section 2 (alternating 12-inch and 24-inch on center). One thousand questionnaire postcards were distributed. Vehicle types consisted of approximately equal numbers of passenger cars and large trucks.

There was an almost 25% response rate to the survey questionnaire with 247 respondents out of the 1000 questionnaires distributed. The objective of the survey was to gauge the users reaction to the centerline rumble strips and to evaluate public opinion on use of centerline rumble strips.

6.1 Survey Questions and Responses

Eight questions were chosen for inclusion in the survey, with most being subjective questions based upon the driver's own impressions of the centerline rumble strips while traveling on the test sections of US-50.

The eight questions and their responses are described further.

1. How often do you travel this section of highway?

There were 29 % of the respondents who traveled the test section monthly followed by 21% who traveled daily, 18% who seldom traveled the route, 17% that take the route 2 to 3 times per week, and 16% that travel the route weekly.

2. Type of vehicle?

The largest percentage of respondents were driving passenger cars – 41%, followed by 23% driving pickups, 19% driving trucks, 12% driving vans and 8% driving SUVs. Some of the respondents traveled the test section on different types of vehicles.

3. Did your tires make contact with the centerline rumble strips?

Thirty nine percent of respondents had made contact with both the continuous and alternating patterns, followed by 38% who had made contact only with the continuous patterns, and 19% who did not make any contact with the centerline rumble strips.

4. Which patterns do you feel were adequately loud to gain your attention?

Thirty six percent of respondents felt that both patterns were loud enough to gain their attention, but almost an equivalent percent of respondents – 34% felt that the continuous pattern was loud enough to gain their attention and 9% felt that the alternating pattern was best for alerting them.

5. Which patterns do you feel adequately vibrated the steering wheel?

The continuous pattern was felt to vibrate the steering wheel better by 36% of the respondents, 34% felt that both patterns provided adequate vibration to the steering wheel and 10% felt that the alternating pattern provided adequate steering wheel vibration.

6. Overall which patterns of rumble strips would you recommend be installed?

A majority of respondents (38%) recommended the installation of the continuous pattern, 18% recommend the alternating pattern and 20% indicated either one would be good.

7. Have you ever fallen asleep or dozed off while driving a vehicle?

Fifty two percent of the respondents replied in the negative, while 31% replied that they had fallen asleep or dozed off once or twice and 15% replied that they dozed off infrequently. Many respondents who reported that they had fallen asleep or dozed off while driving felt that shoulder rumble strips had awakened them.

8. Do you think centerline rumble strips will reduce accidents?

Ninety six percent of the respondents felt that the installation of centerline rumble strips would reduce accidents.

6.2 Respondent Comments

Most of the respondents commented that the centerline rumble strips were a “good”, “terrific” or “excellent” idea, could save lives and should be installed nationwide on all roads. Some felt that they would be helpful in low visibility scenarios – night, fog, rain or snow. There were respondents who felt that continuous rumble strips are better for centerline with the alternate pattern on the shoulder, and this would help them think subconsciously which way to steer while encountering rumble strips. There was one responder who felt the centerline rumble strips needs to be coated with a lot more paint.

The comments of concern included that the centerline rumble strips tend to pull the vehicle to the left, the vehicle sways when crossing the rumble strips at 65 to 70 mph dangerous to cyclists and since people are already familiar with shoulder rumble strips they expressed concern about sudden steering reaction left when hitting centerline rumble strips. There was one person who felt that steering and recovery were difficult with the continuous centerline pattern.

6.3 Kansas Field Study Conclusion

An overwhelming majority of the respondents felt that the centerline rumble strips were good for preventing head-on collision accidents and providing greater safety on Kansas roads. The continuous pattern of centerline rumble strip was felt to be the best pattern to gain the drivers' attention, by being adequately loud and providing adequate vibration, albeit the perception favoring it was only slightly higher than those favoring the alternating pattern.

CHAPTER 7

Overall Conclusions

From the Kansas, K-TRAN study and from the additional study for the NCHRP synthesis, the authors conclude:

- CLRS are a cost-effective tool to mitigate cross over crashes on two-lane roadways.
- Long-term monitoring of the safety, operational and physical impact should be conducted.
- There are a number of concerns that should be studied further; particularly the impact on bicycles. (See following section for recommended future studies.)

CHAPTER 8

Suggestions for Future Studies

Based on the Kansas study and NCHRP synthesis, the KSU researchers make the following suggestions:

- Continue longer-term evaluation of the CLRS that have been installed.
- Develop and promote a proper, standardized methodology for analyzing the safety effectiveness of CLRS.
- Develop and widely disseminate additional training material and/or course in proper statistical methods for analyzing the results of highway safety treatments.
- Conduct research and monitor CLRS locations for long-term pavement performance on various pavement types.
- Conduct research on the long-term effect of CLRS nighttime visibility of striping on dry and wet pavements.
- On two-lane roads with no or limited shoulder and bicycle use, study the effects of CLRS on bicycle safety.
- Conduct additional research to determine if CLRS provide a clear, easily understood message to the driver.
- Determine if CLRS are more cost effective if continuous or if only in no passing zones.
- Determine whether accumulation of water, snow or ice is an issue with CLRS.
- Develop guidelines regarding CLRS installations.

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APPENDIX A

CENTERLINE RUMBLE STRIP STUDY
KANSAS DEPARTMENT OF TRANSPORTATION

Dear Motorist:

The Kansas Department of Transportation (KDOT) needs your help in a special study of CENTERLINE RUMBLE STRIPS on Kansas highways. CENTERLINE RUMBLE STRIPS are indentations grooved in the roadway surface along the yellow lines in the center of the highway that make a vehicle's tires vibrate at normal highway speeds. The purpose of these centerline rumble strips is to alert drivers when their vehicle has wandered LEFT out of the driving lane and into the oncoming lane. This is similar to the way shoulder rumble strips, already installed on many Kansas highways, alert drivers when their vehicle has wandered RIGHT out of the driving lane. To identify possible improvements in the design and use of centerline rumble strips, we need to know how drivers feel about them. Your answers to the attached questions will help provide this valuable information.

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NO POSTAGE
NECESSARY
IF MAILED
IN THE
UNITED STATES

BUSINESS REPLY MAIL
FIRST CLASS MAIL PERMIT NO. 18 MANHATTAN, KS 66502

POSTAGE WILL BE PAID BY ADDRESSEE

KANSAS CLRS SURVEY S01
INDUSTRIAL AND MANUFACTURING
SYSTEMS ENGINEERING
237 DURLAND HALL
KANSAS STATE UNIVERSITY
1700 ANDERSON AVENUE
MANHATTAN KS 66502–9908

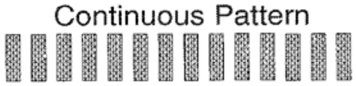
CENTERLINE RUMBLE STRIP STUDY
KANSAS DEPARTMENT OF TRANSPORTATION

Your comments concerning the use and safety of CENTERLINE RUMBLE STRIPS are important. Please complete, detach, and mail the lower portion of this pre-addressed questionaire at your earliest convenience. The information you provide will be kept confidential and only a summary of the results will be available for review.

In appreciation for completing and returning this survey, we would like to send you a free State of Kansas highway map. To receive your map, please provide your mailing address where indicated.

PLEASE ANSWER ALL QUESTIONS AND DROP IN MAIL
NO POSTAGE REQUIRED

TS 1
Continuous Pattern



TS 2
Alternating Pattern

1. How often do you travel this section of highway? ☐ daily
   ☐ 2-3 times per week ☐ weekly ☐ monthly ☐ seldom
2. Type of vehicle: ☐ passenger car ☐ van ☐ SUV ☐ large truck
   ☐ pickup ☐ motorcycle ☐ RV ☐ other (specify) ____________________
3. Did your tires make contact with the centerline rumble strips?
   ☐ continuous pattern ☐ alternating pattern ☐ both patterns ☐ neither

**** IF YOU SELECTED "neither" ON #3, PLEASE SKIP QUESTIONS 4 - 6 ****

4. Which patterns do you feel were adequately loud to gain your attention?
   ☐ continuous pattern ☐ alternating pattern ☐ both patterns ☐ neither
5. Which patterns do you feel adequately vibrated the steering wheel?
   ☐ continuous pattern ☐ alternating pattern ☐ both patterns ☐ neither
6. Overall which patterns of rumble strips would you recommend be installed?
   ☐ continuous pattern ☐ alternating pattern ☐ both patterns ☐ neither
7. Have you ever fallen asleep or dozed off while driving a vehicle? ☐ no
   ☐ yes, once or twice ☐ yes, infrequently ☐ yes, frequently
   If "yes", what woke you up? ______________________________
8. Do you think centerline rumble strips will reduce accidents? ☐ yes ☐ no

COMMENTS____

NAME/ADDRESS____