FINAL REPORT

FHWA-WY-15/02

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Department of Transportation

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Federal Highway Administration

DEVELOPING AN EFFECTIVE SHOULDER AND CENTERLINE RUMBLE STRIPS/STRIPES POLICY TO ACCOMMODATE ALL ROADWAY USERS

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16. Abstract

Lane departure crashes including single-vehicle-run-off-road crashes, opposite direction sideswipe and head-on crashes are considered the most sever crashes and often dominated by sleep deprivation/fatigue, and distracted driving. According to the Federal Highway Administration, 53 percent of annual fatal crashes are attributed to lane and road departures. In Wyoming, lane departure crashes comprised 72 percent of all sever crashes for the years 2008 – 2010. While lane departure crashes are mostly driven by drivers' errors, reduction of the frequency and severity can be achieved by more forgiving roadside and specific countermeasures. Rumble strips/stripes are used by many states as a relatively low cost proven safety countermeasure to reduce or prevent lane departure crashes through providing a vibrotactile and audible warning to inattentive motorists. Although the advantages of rumble strips were generally found to outweigh the disadvantages, several issues and concerns have been identified regarding the implementation of rumble strips; noise, maintenance, and the adverse effects on bicyclists and motorcyclists are among the most recognized concerns.

This study demonstrated that despite the fact that rumble strips have been used for many years, there are no standardized practices used in the U.S. A significant number of states are still working on updating their rumble strips policies; their main goal is to enhance motor vehicle safety while accommodating all road users to the highest practical extent. The information provided in this report and the companion Expert System that was developed as part of this study may provide the necessary background for WYDOT and other transportation agencies when it comes to updating or developing an effective all road users' friendly rumble strips policy.

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METRIC CONVERSION FACTORS

SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
	NOTE: volumes greater than 1000 L shall be shown in m^3			
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	$candela/m^2$	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	$candela/m^2$	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.
(Revised March 2003)

EXECUTIVE SUMMARY

Lane departure crashes including single-vehicle-run-off-road crashes, opposite direction sideswipe and head-on crashes are considered the most sever crashes and often dominated by sleep deprivation/fatigue, and distracted driving. According to the Federal Highway Administration (FHWA), 53 percent of annual fatal crashes are attributed to lane and road departures. In Wyoming, lane departure crashes comprised 72 percent of all sever crashes for the years 2008 – 2010. While lane departure crashes are mostly caused by drivers' errors, reduction of the frequency and severity can be achieved by more forgiving roadside and specific countermeasures. Rumble strips/stripes are used by many states as a relatively low cost proven safety countermeasure to reduce or prevent lane departure crashes by providing a vibrotactile and audible warning to inattentive motorists. Although the advantages of rumble strips are generally found to outweigh the disadvantages, several issues and concerns have been identified regarding the implementation of rumble strips; noise, maintenance, and the adverse effects on bicyclists and motorcyclists are among the most recognized concerns.

The main goal of this project is to develop an effective policy of shoulder and centerline rumble strips/stripes in the State of Wyoming to enhance motor vehicle safety while accommodating all road users to the highest practical extent. Surveys were conducted to assess road users' concerns about rumble strips. Moreover, several issues regarding the use of rumble strips/stripes including: construction, maintenance, and noise are discussed. With the help of the Wyoming Department of Transportation (WYDOT), information regarding the state of practice of rumble strips/stripes in the U.S. was collected. Information was obtained through a review of the literature, online survey and email communications with States' Department of Transportation (DOT). Twenty-nine states responded to the online survey. From the Survey, only four agencies have fully adhered to the NCHRP guidelines; Idaho, Mississippi, Nevada, and New Mexico. Fifteen agencies indicated that they are using the guidelines provided by the National Cooperative Highway Research Program (NCHRP) with some modifications to suit their regions' needs. Seven agencies are using their own guidelines; Alabama, Kentucky, Massachusetts, New Hampshire, North Dakota, Texas, and Wyoming. Among the agencies which took the survey, only Oklahoma responded that they do not have a written policy for rumble strips.

Based on the U.S. DOTs guidelines identified recently from the literature and survey responses, thirty State agencies have already made provisions to accommodate bicyclists.
Only three agencies responded that they do not have any provisions for bicyclists while the remaining eighteen State agencies indicated that they do not have adequate information to address this issue.

The rest of the survey results showed that many DOTs are still updating their rumble strips policies. DOTs which had already been using their own guidelines are now moving forward to accommodate the non-conventional vehicles and nearby residents. About 72 percent of the states are following the NCHRP Report 641 guideline, either strictly or with some modifications. Application criteria and maintenance practices vary by states. Shoulder Rumble Strips (SRS) are more widely used than Centerline Rumble Strips (CLRS) or Edgeline Rumble Stripes (ELRS). Rumble strips are installed mostly on rural roadways since they possess fewer constraints on installation criteria. All of the 29 states which responded to the survey are using SRS and among them 27 states are using CLRS. The use of the combination of SRS and CLRS is not adopted by all the states, only 55 percent of the states are using both types in combination.

Although the NCHRP Report 641 issued guidance on how State agencies can balance the increase in rumble strips implementation while accommodating all roadway users, 16 percent of State DOTs have indicated that their policies do not have any provisions for bicyclists when installing rumble strips, whereas, 42 percent of the DOTs do not consider noise when installing rumble strips. Most of the DOTs commented that they try to avoid installing rumble strips in urban areas to prevent noise. From the survey responses, information gathered in earlier surveys, and from synthesis documents, it was found that 36 states made provisions to accommodate bicyclists, while, only 3 states (Idaho, Maine, and Florida) attempted to accommodate motorcyclists. Maine DOT provides skip pattern on CLRS in rumble strips to facilitate motorcycle lane changes. Idaho DOT uses CLRS only in no-passing zones. The governing criteria ranked by DOTs when a roadway is considered for installing rumble strips are in the following order; area type (urban vs. rural), guardrail, pavement type, pavement thickness, bicycle traffic, motorcyclists, noise, nearby residents.

An Expert System has been developed to provide an interactive easy way to navigate through rumble strips/stripes practices and guidelines in the U.S. It is recommended that the information compiled in the Expert System should be fully utilized when adopting a new policy. It is also recommended that the recent information presented in this report could be used by other DOTs to update their rumble strips policies.

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Final Report
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LIST OF ACRONYMS/ABBREVIATIONS

AADT	Annual Average Daily Traffic
ADT	Average Daily Traffic
AASHTO	American Association of State Highway and Transportation Officials
CLRS	Centerline Rumble Strips
dBA	Decibel
ELRS	Edgeline Rumble Stripes
FHWA	Federal Highway Administration
HSM	Highway Safety Manual
NCHRP	National Cooperative Highway Research Program
SRS	Shoulder Rumble Strips
WYDOT	Wyoming Department of Transportation

CHAPTER 1- INTRODUCTION

Roadway departure crashes are considered as the most severe crashes which include single-vehicle-run-off-road crashes (SVROR), opposite direction sideswipe, and head-on crashes. According to FHWA, [1] 15,307 fatal lane and road departure crashes occurred in 2011 caused 16,948 fatalities. Furthermore, approximately 51 percent of all fatal crashes in the U.S. are caused by roadway departure crashes, and the estimated annual cost of roadway departure crashes is 100 billion dollars. [2, 3] Researchers showed that fatal and injury crashes caused by road departures can be reduced significantly by using shoulder rumble strips/stripes. Head on and opposite sideswipe crashes can be reduced to a lower number by installing centerline rumble strips. Rumble strips is also effective in decreasing total number of crashes. According to the Highway Safety Manual (HSM) 2010, [4] rumble strips are proven to reduce lane and road departure crashes by 10 to 93 percent on different types of roadways.

A rumble strip is a raised or grooved pattern placed on the pavement surface of a travel lane or shoulder. [5] Rumble strips intend to provide motorists with an early audible warning and tactile sensation as they approach a decision point of critical importance to their safety or to alert motorists that their vehicle has partially or completely left the travel lane. When a vehicle passes over rumble strips, a sudden rumbling sound is caused due to the vibration of the vehicle. Rumble strips are also used to warn motorists of upcoming changes like toll plazas, change lanes for a work zone, horizontal curves, stop for a traffic signal or steer back onto the roadway. Additionally, rumble strips are beneficial in guiding motorists in rain, fog, snow or dust. Highway hypnosis, which is caused by long monotonous stretches of straight freeways, can mesmerize and affect driver concentration.[6] This highway hypnosis is mitigated by the use of rumble strips. Although, rumble strips alert motorists of potential decision points or hazards, rumble strips do not identify what type of action is appropriate.

Although the advantages of rumble strips were generally found to outweigh their disadvantages, several issues and concerns have been identified by the FHWA[7] regarding the implementation of rumble strips; noise, maintenance, and the effects on bicyclists and motorcyclists are among the most discussed concerns in the literature. Noise caused by vehicles driving over rumble strips

may affect surrounding residents; many agencies consider noise and environmental impacts before implementing rumble strips near residential or in urban areas. (see references 8, 9, 10, and 11.) Many states have reported that rumble strips installed on pavement in good condition do not pose any maintenance-related concerns; it has been proven that heavy traffic and freeze-thaw cycle of water collecting in the grooves would not cause shoulder rumble strips to crumble faster or crack the pavement. It should be noted that raised rumble strips are usually restricted to use in warmer climate areas where snow removal is not required. While several studies showed that special considerations should be made to alleviate the possible adverse effects posed by rumble strips on bicyclists, (see references 12 -19) a number of studies indicated that no major concerns were identified on the effect of rumble strips on motorcyclists. [20, 21, 22]

BACKGROUND

The primary goal of the recently issued Wyoming Strategic Highway Safety Plan (SHSP) is to reduce fatal and serious injury crashes. Among six identified emphasis areas in the Wyoming SHSP 2012, [23] lane and road departure crashes received the first priority. Lane departure crashes include single-vehicle-run-off-road crashes (SVROR), opposite direction sideswipe and head-on crashes. It is worth mentioning that these types of crashes are considered the most sever crashes and often dominated by sleep deprivation/fatigue, and distracted driving. (see references 8,9,10, and 11.) According to the FHWA, [1] 53 percent of annual fatal crashes are attributed to lane and road departures. The Wyoming SHSP 2012 indicated that lane departure crashes comprised 72 percent of all sever crashes for the years 2008 – 2010. While lane departure crashes are mostly driven by drivers' errors, reduction of the frequency and severity can be achieved by more forgiving roadside and specific countermeasures. Rumble strips/stripes are used by many states as a relatively low cost proven safety countermeasure to reduce or prevent lane departure crashes through providing a vibrotactile or audible warning to inattentive motorists. Shoulder and centerline rumble strips/stripes have a demonstrable impact on reducing the frequency of Single Vehicle Run-Off-Road (SVROR) crashes, opposite direction side-swipe and head-on crashes. [28, 29, 30] According to the Highway Safety Manual 2010, [4] rumble strips are proven to reduce lane departure crashes by 10 to 93 percent on different types of roadways.

The Federal Highway Administration considers the various rumble strips as effective in counteracting risks posed by inattentive drivers. The various documents concluded that the SRS, CLRS, and the TRS contribute significantly to a reduction in roadway crashes resulting from unfocused or distracted drivers. [4, 26, 27]

The FHWA requires the design and installation of rumble strips that accommodate all road users. Cyclists are uniquely identified as being negatively affected most by rumble strips in situations where rumble strips are constructed on the shoulder without leaving room for cyclists. The cyclists are forced to ride on the travel lanes where they are exposed to more dangers from vehicular traffic. To prevent or reduce the negative impact of rumble strips on cyclists and other road users, the American Association of State Highway and Transportation Officials (AASHTO), FHWA and some State Departments of Transportation (DOTs) have provided guidelines for installing rumble strips on roadways.

Several research and studies have been carried out on rumble strip/stripes that acknowledged the efficiency of rumble strips as a capable deterrent of some crash types. National Cooperative Highway Research Program (NCHRP) [31] documents statistically significant reductions in single run-off-road injury crashes with the implementation of shoulder or edge rumble strips. A reduction of 10 to 24 percent was recorded on rural freeways and 26 to 46 percent on two-lane rural roads. Similar studies on drift-off-road crashes in Michigan and New York also recorded crash reductions of 38 and 79 percent respectively. For centerline rumble strips, statistically significant reductions in injury crashes of 38 to 50 percent was recorded for rural areas, and 37 to 91 percent for urban two lane roads. Studies in Iowa and Minnesota also indicated a significant reduction in severe injury crashes at minor road stop-controlled intersections. [32]

Beyond the prevention of crashes, the installation of rumble strips was also identified as being an effective mean of locating the travel lane during extreme weather conditions that result in low visibility. [33] The vibration and noise made by the rumble strips check drivers from driving off the travel lane during low visibility.

The FHWA [34] also listed longitudinal rumble strips and stripes on two-lane roads as one of nine proven safety countermeasures.

In a bid to reduce the number of critical crashes on Wyoming's highways, the Wyoming Strategic Highway Safety Plan (SHSP) analyzed Wyoming State's crash data to identify six areas where there are opportunities to reduce critical crashes. The identified areas were Roadway Departure Crashes, Use of Safety Restraints, Impaired Driving, Speeding, Young Drivers, and Curve Crashes. Of the six areas determined from the data, lane departure consistently produced the highest number of crashes from 2002 to 2010 as illustrated in figures 1 through 6.

Crashes associated with lane departures/run-off-the-road result from driver fatigue, impaired driving, speeding, and distracted driving. These crashes were determined to have contributed to 72 percent of all critical crashes. In a bid to reduce the occurrence of these types of crashes, one of the recommendations by the Wyoming SHSP was to continue the implementation of the rumble strip policy on highways.

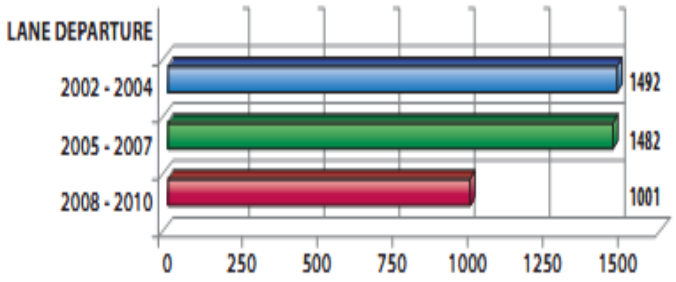

Figure 1: Lane Departure Crashes History in Wyoming

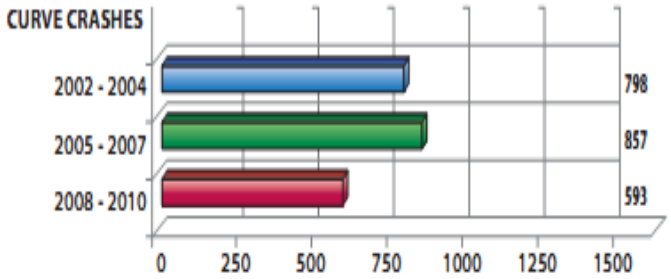

Figure 2: Curve Crashes History in Wyoming

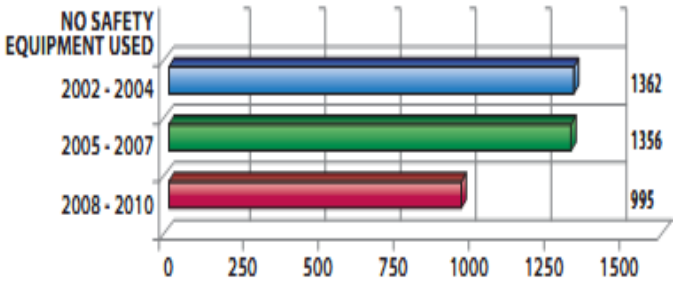

Figure 3: Safety Equipment Involvement in Crashes

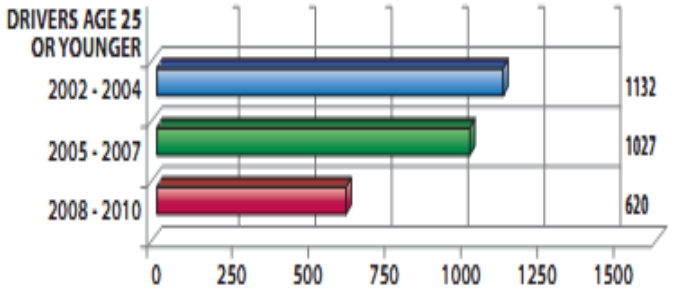

Figure 4: Crashes Involving Younger Drivers

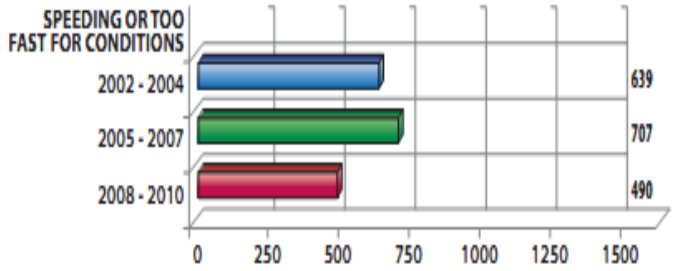

Figure 5: Crashes History Involving Speeding

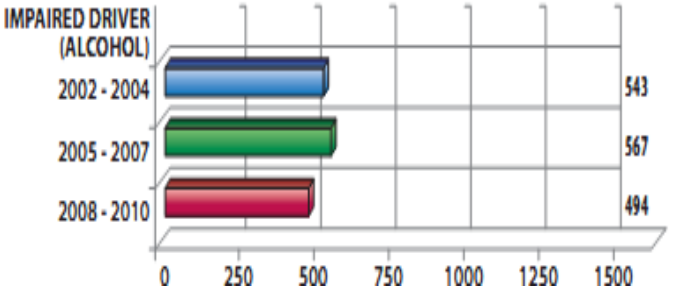

Figure 6: Alcohol Involvement in Crashes

STUDY BENEFITS

The Wyoming Strategic Highway Safety Plan recognized the importance of rumble strips in improving safety on roadways and therefore recommended continued implementation of rumble strips/stripes. However, rumble strips may pose some concerns to residents, bicyclists and motorcyclists that may become more serious with the increased implementation of rumble strips. The objective of this study was to develop recommendations, guidelines, and policies for the implementation of rumble strips/stripes to ensure that there is a significant reduction of negative impact to road users even with increased usage of rumble strips by WYDOT.

PROJECT GOALS

As shown in figure 7, two main goals were to be achieved in this study. The first goal was to review and amend the existing practices and policies as well as providing guidelines to update the Standard Plans of rumble strip/stripes implementation. The second goal of the study was to determine the preferences and practices of surrounding states in the Rocky Mountains and Plains Region as well as to catalogue the concerns and preferences of residence, cyclists, and motorcyclists with regards to rumble strips.

To achieve the first goal, a review of practices and recommendations of various transportation agencies in the U.S. and Canada was conducted considering the following factors:

- Review of policy and installation warrants.
- Implementation of guidelines and placement standards.
- Designs of rumble strip; milled, rolled, dimension and offset, and safety trends.
- Effectiveness in reducing crashes.
- Effect on roadway users: drivers, bicyclists and motorcycle riders.
- Effects on nearby residents in urban areas.
- Effect of noise and environment.
- Impacts on road maintenance, drainage, and snow removal.

The second goal was achieved through a self-reported (stated preference) surveys which were conducted to examine residence, bicyclists, and motorcyclists responses and/or experiences with rumble strips.

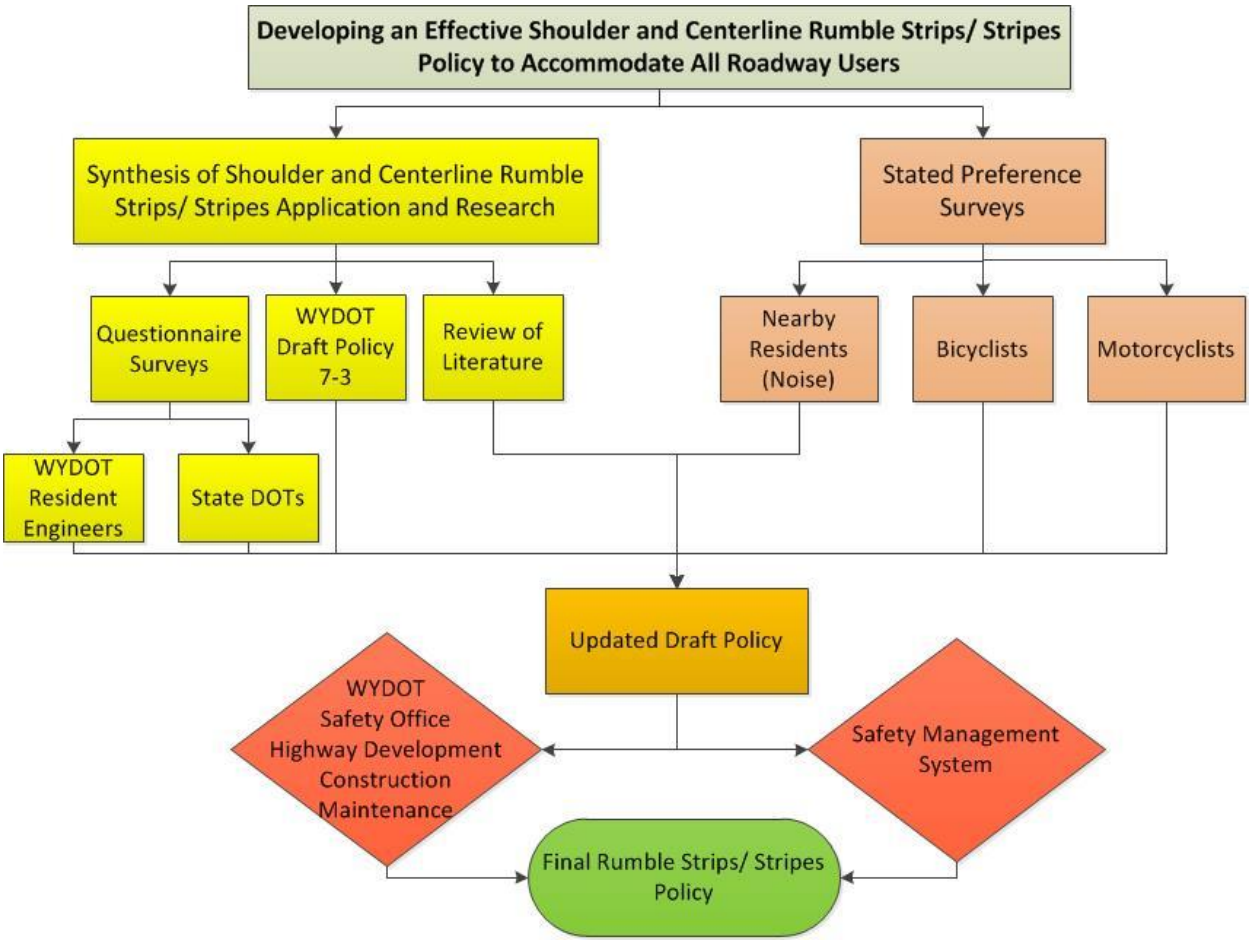

Figure 7: Project Flowchart

RUMBLE STRIPS/STRIPES IN THE U.S.

Types of Rumble Strips

There are four commonly used types of rumble strips. Each of these four types produces different levels of vibrations and noise:

- Rolled in rumble strips.
- Milled in rumble strips.
- Formed rumble strips.
- Raised rumble strips.

They differ primarily by method of installation, their shapes, and sizes.

Rolled in rumble strips were the most common in the U.S. and Canada in the last few decades. Due to the advantages of milled in rumble strips over rolled in rumble strips, most of the states have switched to milled in rumble strips installation method. The four rumble strip types are described in the following sections.

Rolled in Rumble Strips

Early on, most of the rumble strips installed were rolled in rumble strips. In these types of rumble strips, a series of steel pipes were welded to rollers and narrow depressions were made by pressing the roller into the road while the asphalt was still hot, so that the roller could indent the asphalt. Nearly all the highways currently using the milled cut had been previously installed rolled in rumble strips. [(35)]

The advantage of this type of rumble strip was being inexpensive. The strips are created during the normal course of construction or reconstruction at the compaction stage. Rolled-in patterns had some success in reducing drift-off accidents; however, the disadvantages of this type of strips are that installation can only be done during the construction or reconstruction process. Also, the rolled-in pattern has presented critical maintenance and construction problems. For example, a reduction in shoulder asphalt density is caused due to non-uniform compacting during construction. Premature degradation of the shoulder occurs due to the increased void formed along the joints. [(36)]

Milled in Rumble Strips

Milled rumble strips are simply grooves of specified dimensions cut into the pavement by a milling machine; the grooves themselves are placed transverse to the direction of travel, while a continuous series of these grooves runs longitudinally with the roadway, allowing for vibratory

and auditory effects when the rumble strips are struck by a vehicle tire. Many states prefer to use milled rumble strips because it is easier to install on existing asphalt, new asphalt, and Portland Cement pavements and shoulders. Also, they have an insignificant effect on the integrity of the pavement structure.

FHWA published a technical advisory [33] on SRS in 2001 recommending milled SRS as the preferred type due to its superior performance in providing a loud, jarring warning over rolled-in rumble strips. The advisory reported that milled rumble strips is 12.6 times rougher and 3.4 times louder than rolled in rumble strips. Though, milled rumble strips are more expensive than other types, all agencies are using milled in method as it can be installed on an existing roadway.

Formed Rumble Strips

Formed rumble strips are formed by pressing forms into concrete shoulders while the concrete being constructed. Formed rumble strip are 32 mm deep and 40 mm wide of rounded or V-shaped grooves.

Raised Rumble Strips

Raised rumble strips are usually wide, rounded or rectangular markers or strips that adhere to new or existing pavements. Raised buttons are used by some agencies for raised rumble strips. Different materials that have been used include asphalt bars and rubber like material or plastic reflectors. The height of raised rumble strips can vary between 6 mm and 13 mm, therefore, its use is usually restricted to warmer climate areas where snow removal is not required. [37] Bicyclists may prefer this type over the milled or formed strips because there is little or no disruption to the rider. The raised rumble strips can be applied at any time; the road does not need to be undergoing construction or reconstruction. The disadvantage of this type of rumble strip is that, in snow belt areas, snowplows tend to remove them. Additionally, the cost of raised rumble strips installation is higher than formed strips.

Applications of Rumble Strips

Based on the application, rumble strips are categorized into four basic categories:

- Shoulder Rumble Strips (SRS)/Edgeline Rumble Stripes (ELRS).
- Centerline Rumble Strips or Stripes (CLRS).
- Midlane Rumble Strips.
- Transverse Rumble Strips or Stripes (TRS).

Shoulder Rumble Strips/Edgeline Rumble Stripes

SRS (figure 8) are a series of raised or milled longitudinal safety features that are installed near the outside edge of paved roadways with the purpose of alerting inattentive drivers when they are departing from the travel lane. [33] SRS are placed on roadways to improve roadway safety that is related to unintentional drift over the road edge. Occasionally, a type of shoulder rumble strip is built by placing the rumble strips exactly at the edge of the travel lane and coating them with edge line pavement markings and this type is called Edge Line Rumble Stripes (figure 9). This type of rumble stripes increases the wet/night time visibility of the edgeline pavement markings which prevents drivers from leaving the edge of the road.

Centerline Rumble Strips or Stripes

CLRS as shown in figure 10 are also a series of raised or milled longitudinal safety features but unlike Shoulder Rumble Strips, they are placed at or near the centerline of a paved roadway. [38] CLRS are installed to improve roadway safety in relation to inattentive drivers drifting across the centerline of the road.

Midlane Rumble Strips

Midlane rumble strips are still a conceptual design which are placed in the center of the travel lane. They serve two functions of the SRS and CLRS combined. According to the NCHRP Report 500, [39] midlane rumble strips could help in reducing cross-over and run-off-road crashes. Midlane rumble strips are similar in design to shoulder rumble strips, but installed in the center of the travel lane instead of the edge of the shoulder. Midlane shoulder rumble strips are promising in eliminating the adverse effect on bicyclists on roads with no or narrow shoulders, however, they could be a concern for motorcyclists. After successful experimentation and evaluation, the effectiveness can be measured of this new type of rumble strips.

Transverse Rumble Strips or Stripes

TRS (figure 11) consist of a series of raised or milled safety features crossing the roadway surface to provide a timely and audible warning for drivers when approaching a spot where a deceleration or a stop action is required. [32] The primary purpose of the TRS is to alert drivers when they are approaching intersections, toll plazas, horizontal curves, work zones, or any other unexpected conditions. [31]

Figure 8: Shoulder Rumble Strips

Figure 9: Edgeline Rumble Stripes

Figure 10: Centerline Rumble Stripes

Figure 11: Transverse Rumble Strips

Layout of Shoulder and Centerline Rumble Strips/Stripes

The dimensions used for rumble strips can be better understood from the layout presented by the FHWA. [33, 38] In figures 12 and 13, the dimension longitudinal to the road is the width (C) of the rumble strips, and the dimension transvers to the road is length (B). The offset (A) is defined as the distance from the edge of rumble strips to the edge of the travel lane. The spacing between rumble strips grooves (E), the depth of the grooves (D), and (F) is the gap provided to accommodate bicyclists in a skip pattern rumble strips.

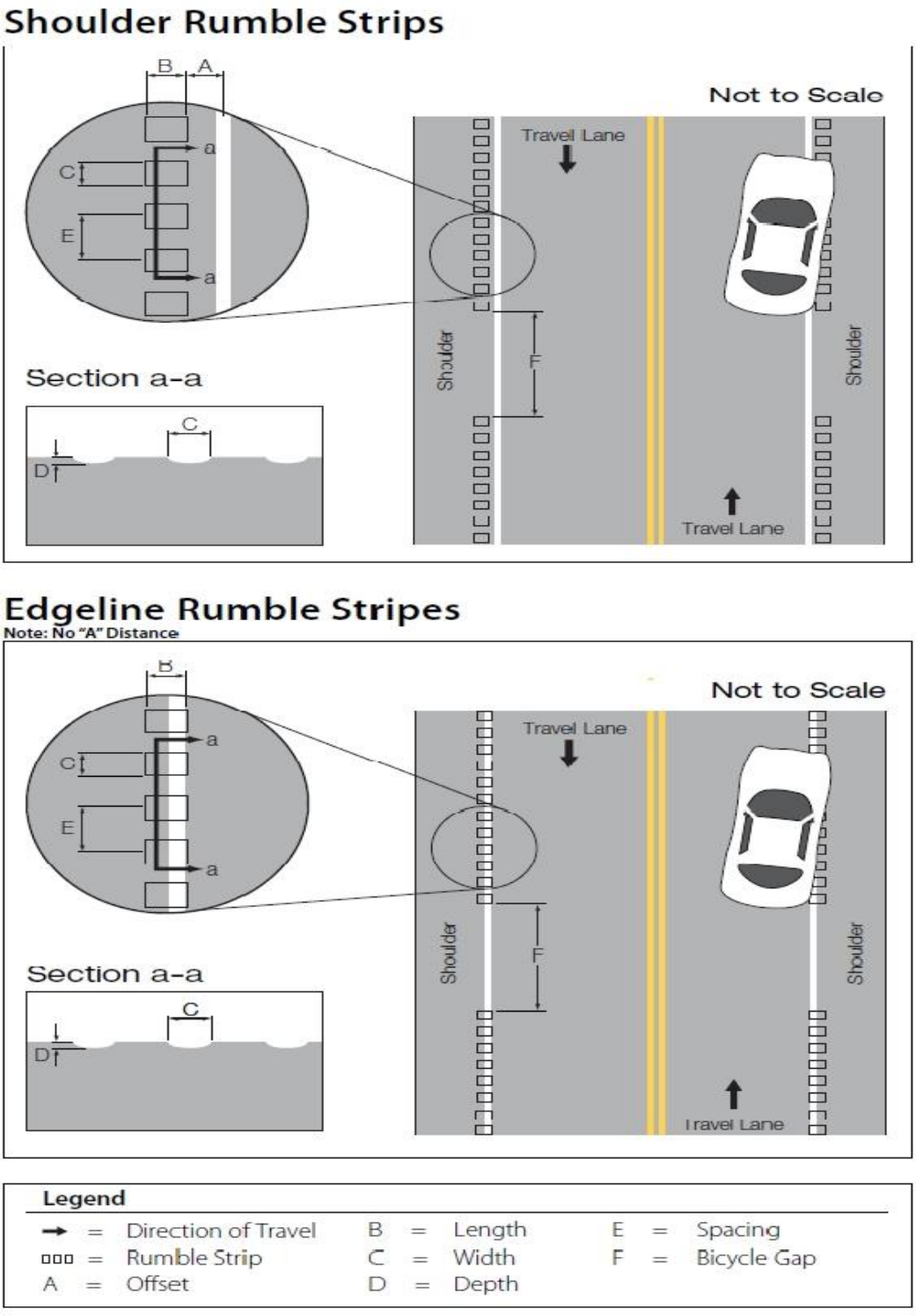

Figure 12: Layout of Shoulder Rumble Strips/Stripes (Source: FHWA NCHRP Report 641)

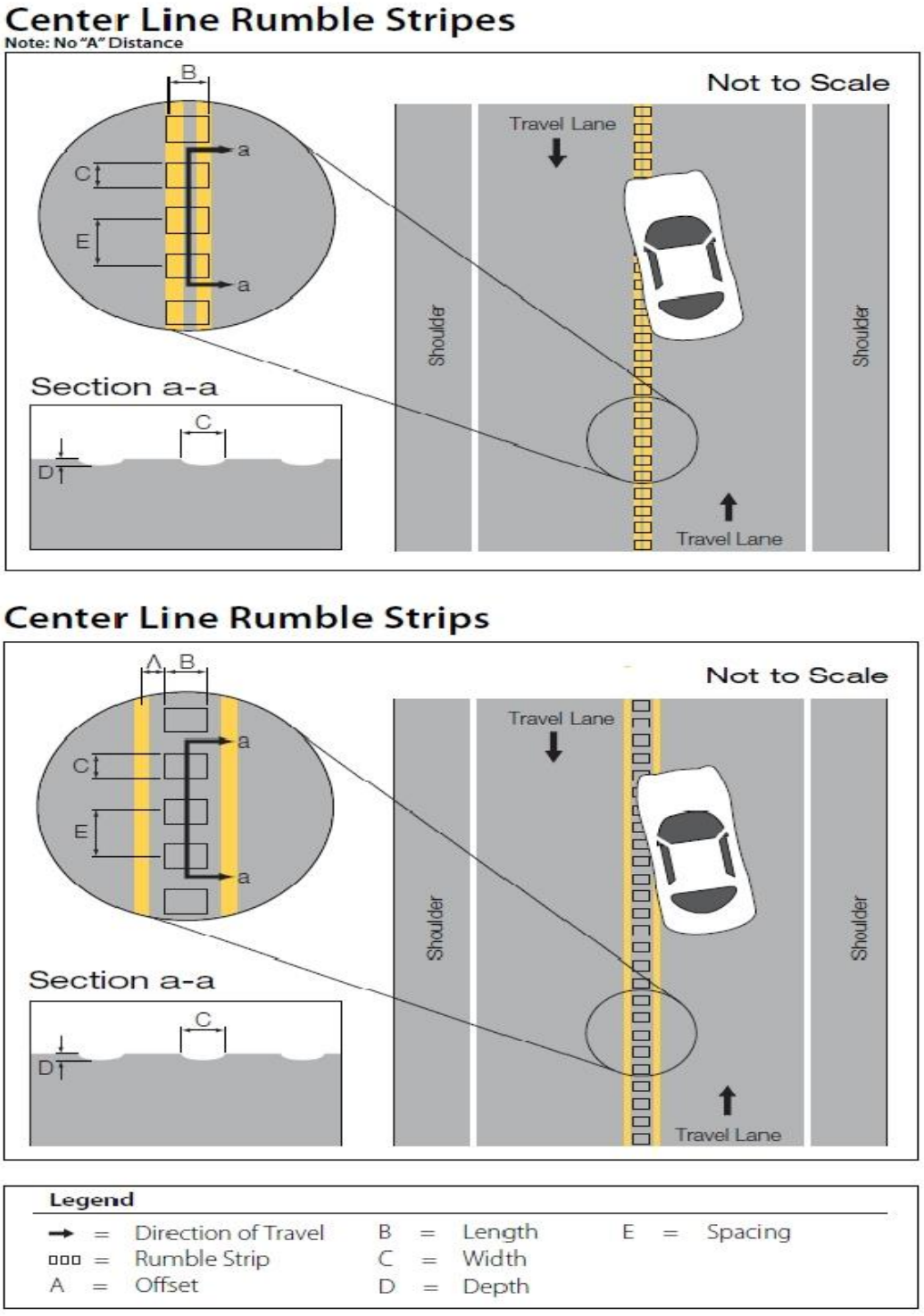

Figure 13: Layout of Centerline Rumble Strips/Stripes (Source: FHWA NCHRP Report 641)

CHAPTER 2- LITERATURE REVIEW

RUMBLE STRIPS/STRIPES PRACTICE IN OTHER STATES

In 2009, the National Cooperative Highway Research Program (NCHRP) published the NCHRP Report 641; which provides guidance for the design of shoulder and centerline rumble strips and stripes. One of the main objectives of the NCHRP Report 641 was to minimize the adverse effects of rumble strips on non-conventional vehicles and nearby residents. Many states have started following the guideline provided by the NCHRP to install their rumble strips. They have updated their rumble strips policy to implement the recommendations from the NCHRP. Some states are still using their own guideline policy. Nonetheless, few states still do not have any rumble strips policy.

With the help of WYDOT, information regarding the state of practice of rumble strips/stripes in the U.S. has been collected. Also, data were collected thorough review of the literature, online survey questionnaire, and email communications with the States' DOTs. Thirty State DOTs responded to the online survey. The summary of the results are shown in figure 14 indicating agencies that are following the NCHRP, following the NCHRP with some modifications, not following the NCHRP, or their information are not available. Four agencies are following the NCHRP guideline fully; Idaho, Mississippi, Nevada, and New Mexico. Fourteen agencies indicated that they are using the guidelines provided by the NCHRP with some modifications to suit their regional needs as illustrated in figure 14. Seven agencies are using their own guideline**;** Alabama, Kentucky, Massachusetts, New Hampshire, North Dakota, Texas, and Wyoming. Among the agencies which took the survey, only Oklahoma responded that they do not have a written policy for rumble strips.

Based on the DOTs guidelines identified recently from the literature and survey responses, figure 14 was prepared to illustrate whether or not a DOT has a provision to accommodate bicyclists. Many DOTs have already modified their rumble strips policy in order to accommodate bicyclists. From the survey and literature, it was found that 36 state agencies have already made provisions for bicyclists in their rumble strips policy. Only three agencies have

responded, they do not have any provisions for bicyclists and for the remaining 18 State DOTs, the information was not available or comprehensive enough to address this issue.

The following sections and tables 1 and 2 provide a summary about rumble strips/stripes guidelines and provisions implemented to accommodate other roadway users in the U.S. and two provinces in Canada, i.e. Alberta and British Columbia.

Alaska

Alaska DOT has been using rumble strips since 2000. They had their first policy on rumble strips in 2001. In 2009, they have modified there previous policy to accommodate bicyclists and to address the noise issue.

Shoulder Rumble Strips

Their current practice is using a depth of 1/2 inch, width of 7 inches, and length of 16 inches. Rumble strips are only used if speed limit is 50 mi/h or higher. They use some criteria on where rumble strips should not be installed, e.g. on pavement less than 2 inches thickness and unpaved roads, between through lanes and turning lanes, on bridge decks, bridge approach slabs, on roads that are programmed for overlay, rehabilitation, or reconstruction.

Centerline Rumble Strips

Alaska DOT is also using centerline rumble strips on undivided rural highways, if there is a history of head-on/crossover crashes. Unlike, the shoulder rumble strips, they use 3/8 inch deep and 12 long strips. Centerline rumble strips are installed in both passing and no-passing zone. Few exceptions, where centerline rumble strips are not installed including previous consideration, in urban areas and where combined lane and shoulder width in each direction is less than 14 feet.

Considerations for Other Roadway Users

Alaska provides 12 feet gaps in 80 feet cycles. Gaps spacing are reduced to 60 feet for routes with heavy bicycle traffic.

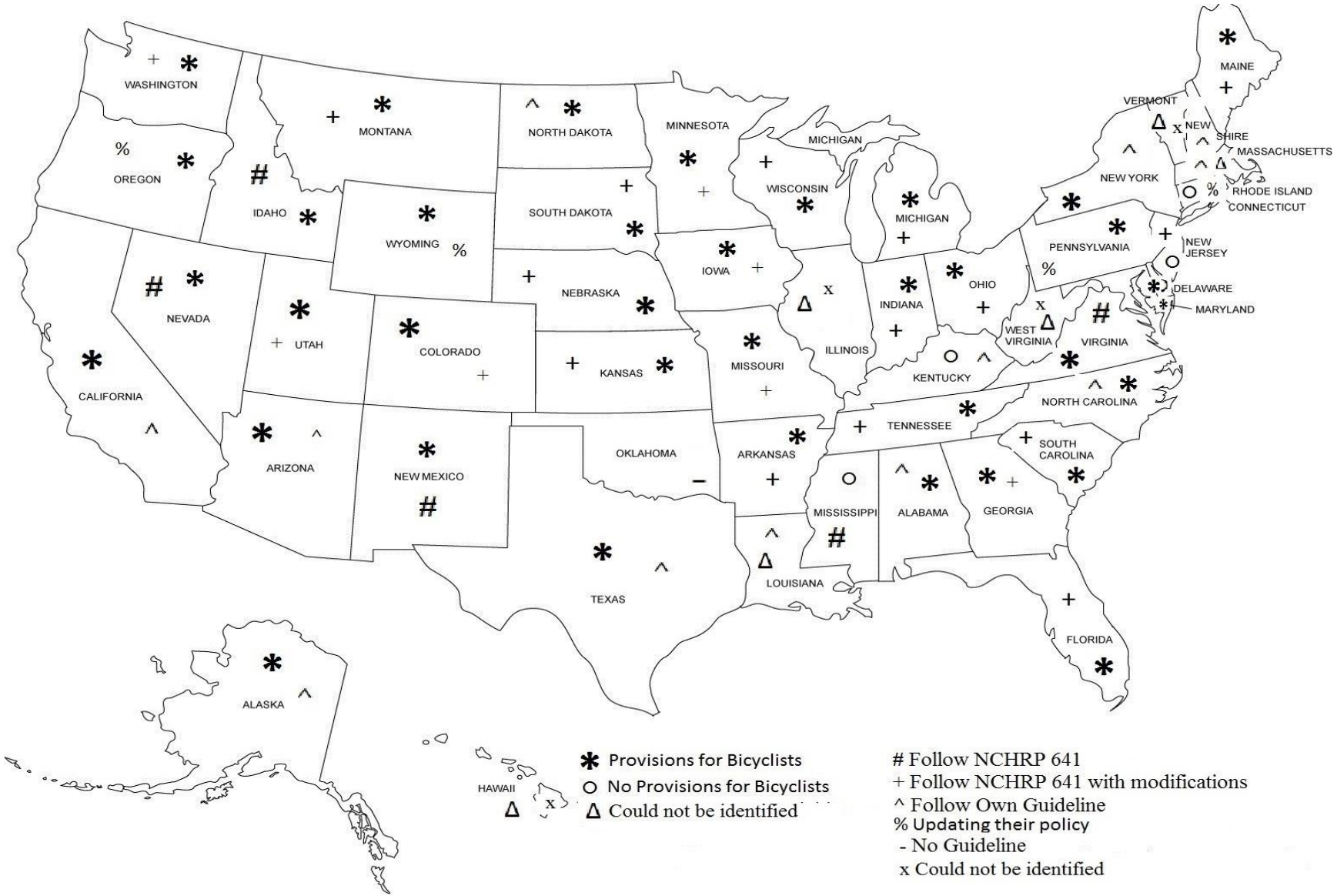

Figure 14: States with Provisions for bicyclists in Rumble Strips Guideline

Arizona

In Arizona, rumble strips are used in both divided and undivided roadways. Different dimensions are used depending on the types of roadway. Requirements for rumble strips installation also vary with the type of roadway. [44, 45]

Shoulder Rumble Strips

For divided roadways, two groove widths are recommended depending on the shoulder width. When the shoulder width is 6 feet or greater, 12 inches groove length is recommended. On the other hand, reduced groove length of 8 inches is recommended for roads with shoulder width less than 6 feet. Same groove width is recommended for left shoulder. The other dimensions of the strips are recommended as 7 plus or minus 1/4 inches wide, 5 plus or minus 1 inches spacing, and 3/8 plus or minus 1/8 inch deep.

For undivided roadways, if the shoulder width is greater than or equal to 4 feet, a 6 inches SRS length is used. For divided highways with greater than or equal to 6 feet right shoulder width, 12 inches of RS length is used while 8 inches length is utilized with less than 6 feet right shoulder width. Arizona DOT (AZDOT) also updated the rumble strips spacing to 7 inches instead of 5 inches in their revised policy.

Continuous rumble strips are recommended on all controlled access highway. For non-controlled access highways, the installation needs to be justified by an evaluation based on crash history. In urban and developed areas, continuous SRS are not recommended. Installation of SRS in suburban and developing areas should be evaluated on case by case basis.

Centerline Rumble Strips

Arizona DOT installs CLRS between pavement markings on rural multilane undivided and rural two lane highway. The dimensions are, 6 plus or minus 1/4 inches wide, 7 plus or minus 1/4 inches long, 5 plus or minus 1 inches spacing, and 3/8 plus or minus 1/8 inch deep.

Considerations for Other Roadway Users

AZDOT was one of the early states that examined different ways to accommodate bicyclists, [46] skip patterns were recommend to permit bicyclists to cross shoulder rumble strips without having to encounter the rumble strip pattern. Based on field experiments, a periodic 10-12 feet gaps were recommended at spacing of 40-60 feet on all non-controlled access highways. Also, a clear shoulder width of at least 3 feet and 5 inches from outside edge of the rumble strips to the front face of the barrier/guardrail was recommended. Recently, they have revised their policy for bicyclists to install rumble strips on roads with at least 5 to 6 feet shoulder considering the presence of guardrail. Additionally, recent revision recommended using 3/8 inch deep groove instead of 1/2 inch on non-controlled access roadways. The length of the rumble strip grooves should be reduced to as narrow as 6 inches on undivided roads with shoulder width less than 4 feet to increase the available clear width for bicyclists.

Arkansas

Arkansas DOT has been using rumble strips to reduce roadway departure crashes since 2007. In 2012, they have developed a complete policy for the use of rumble strips to accommodate all road users, and nearby residential areas for rumble strips installation. Shoulder and centerline rumble strips both are used in Arkansas.

Several factors were given high importance before choosing location to install rumble strips. These factors include:

- Urban vs. Rural Areas
- Noise
- Type and Condition of Shoulders
- Bicyclists

The policy recommended not installing rumble strips in urban areas, instead to primarily focus on rural areas or less developed areas where there is a lower concentration of driveways, residential areas, and commercial development near roadways.

Shoulder Rumble Strips

SRS are installed on both inside and outside shoulders of rural divided highways with full access control and partial access control. SRS are used on undivided rural highways too. If the shoulder is too narrow to install rumble strips, shoulder rumble stripes are installed. Shoulder rumble stripes should be installed if only the shoulder width is less than 5 feet 4 inches and speed limit is greater than 45 mi/h. Heavy truck traffic should be considered too, while installing rumble strips.

Centerline Rumble Strips

The guideline recommends installing CLRS on selected rural highways with high lane departure crashes history.

Considerations for Other Roadway Users

According to the guideline, 12 feet gap should be provided in 60 feet cycle with 3/8 inch depth instead of 1/2 inch to accommodate bicyclists. The 3/8 inch depth can provide enough level of vibration to motorists while better accommodating bicyclists.

California

In California, rumble strips are designed to accommodate non-conventional vehicles. In 2011, the policy was revised to accommodate bicyclists and noise issue. The policy discourages installing rumble strips in residential areas or on deteriorated pavements without engineering judgment.

Shoulder Rumble Strips

In the last revised policy, the length, width, depth and other dimensions of rumble strips were redesigned. The policy recommends width of 5 inches (plus or minus 1) groove with depth of 5/16 inch (plus or minus 1/16) and spacing of 12 inches (plus or minus 2), which are traversable by bicyclists. If there is not enough shoulder width available, the guideline prohibits installing rumble strips or recommends widening the shoulder.

Centerline Rumble Strips

California DOT uses CLRS on the undivided highways as a measure to reduce cross centerline collisions. CLRS are installed between lanes below painted medians. CLRS are used on both passing and no passing zones. CLRS are discontinued at all public street intersections.

Colorado

Colorado DOT is one of the few DOTs who started working on bicycle friendly rumble strips in early 2000. In 2001, Outcalt [20] studied the comfortability of bicyclists on rumble strips by varying various dimensions of rumble strips, e.g. width, depth, length, spacing, etc. Four new configurations were installed along Interstate-70 on an overlay project. Additionally, five sections similar to Colorado DOT standards were installed in the same project. A group of volunteer bicyclists were asked to ride the various configurations. The data about bicycle vibration, sound level of motor vehicles, and vibration in motor vehicles were gathered. Based on all the data collected, the recommendations were made.

Shoulder Rumble Strips

Based on Outcalt's study, it was recommended to use groove depth of 3/8 inch (plus or minus 1/8) with spacing of 12 inches and to provide 12 feet gap in 60 feet cycle rumble strip to accommodate bicyclists. Until now, this is the most common practice in most of the states. It was also recommended to provide some form of warning to warn the bicyclist about the rumble strips ahead. Also, it was recommended to educate the bicyclist about where to expect the rumble strips and what to do when encounter them.

The current practice in Colorado is a reflection of Outcalt's study. If the shoulder width is less than 6 feet, shoulder rumble strips are not installed in those sections. According to their guideline, SRS should be omitted at turn and auxiliary lanes, road approaches, residences, and 250 feet before road intersections.

Centerline Rumble Strips

It is recommended to use CLRS of 7 inches wide, 12 inches center to center spacing and 5 inches gap. After doing a before and after study for CLRS, 34 percent and 36.5 percent reductions were found in head-on and sideswipe accidents consecutively. They have also found that, rumble strips do not have any detrimental effect on pavement life.

Connecticut

Shoulder Rumble Strips

SRS are mostly installed in limited access highway. Rumble strips are installed on roads with minimum 3 feet shoulder width. The recommendation regarding shoulder width has been emphasized as the strips cannot be cut on the pavement with a proper offset on a shoulder width of less than 3 feet. The strips dimensions provided are 16 inches long, 7 inches wide, and 1/2 inch to 5/8 inch deep, with spacing of 12 inches. For narrower left shoulders, 6 inches offset is recommended. Strips are discontinued on exits and entry ramps. Also, rumble strips are terminated on bridge decks.

Centerline Rumble Strips

CLRS are installed on rural roadways with Average Daily Traffic (ADT) of 2000 vehicle per day with posted speed limit of 45 mi/h or greater. The roads should have a minimum width of 13 feet from the centerline of the road to the edge of pavement. To install rumble strips, the pavement condition should be ‘good’ or an overlay project was done in last three years. The segment should be at least one mile long for CLRS installation. CLRS will be terminated 25 feet before any break in the centerline, any crosswalk, start of passing zone, and start of a two way left turn.

CLRS are installed within pavement markings. The recommended dimensions are 12 plus or minus 1/2 inches long, 7 plus or minus 1/2 inches wide, 3/8 inch to 1/2 inch deep, with a 24 plus or minus 1/2 inches spacing.

Noise

Connecticut used to install rumble strips with 6 inches offset in the right shoulder. After receiving several complains from the residents, it was modified to 12 inches to decrease the incidence of vehicles falsely traversing the rumble strips.

Delaware

Shoulder Rumble Strips

The typical shoulder rumble strips dimensions used in Delaware were about 16 inches wide, 1/2 inch deep, and placed approximately 12 inches outside from the edge line. But, nowadays, they have moved to more bicycle friendly designs by reducing the width to 12 inches, depth to 3/8 inch and placing them just 8 inches from the travel lane. Like other states, they also do not install rumble strips close to the driveway entrances and intersections.

Centerline Rumble Strips

Delaware DOT (DelDOT) recommends installing CLRS in all conventional two-lane and undivided multilane roadway where crossover or head-on crash rates along the section is higher than statewide or national average. Minimum of 10 feet lane width is required to install rumble strips. CLRS use in bridge decks is not recommended.

Considerations for Bicyclists

To accommodate bicyclists, minimum 5 feet of clear shoulder width is required. If the shoulder width cannot be maintained, a bicycle friendly edgeline rumble stripes with 12 feet gap in 40 feet cycle are recommended.

Noise

Considering the noise produced from rumble strips, DelDOT discourages the use of rumble strips in high density residential areas and limits using them in freeway and rural roads.

Idaho

Shoulder Rumble Strips

Idaho uses SRS on their rural freeways, rural divided multilane highways, and rural two-lane highways.

On the divided highways, continuous strips/stripes are installed on left shoulders and intermittent type strip/stripes are recommended on right shoulders to allow bicyclists. Rumble strips are terminated at exits and entry ramps. On rural two-lane highways, bicycle gaps are provided on both shoulders.

Three different configurations are used based on the available shoulder widths:

- On roadways with 2 feet to 4 feet shoulder rumble stripes are recommended. The dimension should be 6 inches long, 6 inches wide, and 3/8 inch to 1/2 inch deep. The stripes should be installed 3 inches inside from the edgeline.
- On roadways with 4 feet to 8 feet shoulder, strips or stripes can be used. The recommend dimensions for strips are 12 inches long, 7 inches wide, and 1/2 inch to 5/8 inch deep with spacing of 12 inches. When stripes will be installed, the dimensions should be 12 inches long, 6 inches wide, and 3/8 inch to 1/2 inch deep and the edge of the stripes should be installed 3 inches inside the edgeline as illustrated in Idaho standards drawings.
- Strips or stripes both can be used on roadways with more than 8 feet shoulder. The recommend dimensions for strips are 16 inches long, 7 inches wide, and 1/2 inch to 5/8 inch deep with spacing of 12 inches. When stripes are installed, the rumble strip dimensions should be 16 inches long, 6 inches wide, and 3/8 inch to 1/2 inch deep and the edge of the stripes should be installed 3 inches inside the edgeline.

Centerline Rumble Strips

Idaho uses CLRS on their rural multilane undivided and rural two-lane highways. Rectangular shape strips are milled within pavement markings. Pavement markings will be placed over the installed and cleaned strips. The dimensions used are 12 inches long,

7 plus or minus 1/2 inches wide, 1/2 inch to 5/8 inch deep, with 12 plus or minus 1/2 inches spacing. CLRS should be discontinued in passing zone unless approved by an engineer. Also, CLRS are not allowed on bridges or approach slabs.

Considerations for Bicyclists

To allow the bicyclists on the roadway, on a 60 feet cycle, 12 feet-6 inches gaps are provided on all rural two lane highway and divided highways.

Indiana

Shoulder Rumble Strips

SRS are installed on rural freeway (interstate or non-interstate), rural multilane divided non-freeway, rural two-lane, and multilane undivided roads.

For freeways, continuous strips should be installed. On rural two-lane and multilane undivided roads with speed limit greater than 50 mi/h, CLRS and ELRS are recommended to be installed in combination. For the same types of roads with speed limit less than 50 mi/h, neither CLRS nor ELRS are recommended with the exception on specific segments with significant history of run-off-road, side swipe, and head-on crashes. Rural multilane divided non-freeways with speed limit greater than 50 mi/h should have ELRS on left or right, or on both shoulders. ELRS are not generally recommended on rural multilane divided non-freeways with posted speed limit less than 50 mi/h.

Edgeline Rumble Strips (ELRS) should be installed when the paved shoulder width is more than 2 feet and should not be installed in urban areas or on roadways with two-way left turn lanes. When installed in combination with CLRS, minimum lane width should be 11 feet.

The recommended strips dimensions should be 16 inches long, 7 inches wide, 1/2 inch deep with spacing of 12 inches.

Centerline Rumble Strips

CLRS are recommended for use on rural two-lane, and rural multilane undivided roads. When installed in combination with ELRS, minimum lane width should be 11 feet. For other cases, minimum lane width should not be less than 10 feet. CLRS should not be installed on urban segments.

Consideration for Bicyclists

To accommodate bicyclists, on rural segments with significant bicycle traffic, paved shoulder width should be of minimum 4 feet to install ELRS. Also, 20 feet gaps should be provided in 100 feet cycles.

Iowa

Shoulder Rumble Strips

Shoulder rumble strips are not recommended where the total road width in either direction is less than 12 feet including shoulder width. If the total width is 14 feet, intermittent type of rumble strips is used. Continuous rumble strips are used on both outside and median shoulders in interstate. In urban or residential areas prior to 660 feet rumble strips are discontinued.

Centerline Rumble Strips

Centerline rumble strips are installed if the roadway falls under either one of the following conditions:

- All two-lane primary roads with greater than 3,000 design year ADT with 2 feet or wider shoulders and at least 11 feet lane widths.
- All undivided highways with 2 feet or wider shoulders and at least 11 feet lane widths, as they are resurfaced.

Considerations for Other Roadway Users

Iowa provides gaps for bicyclists to cross over on roads with rumble strips. Twelve feet gaps are provided in each 60 feet cycle to accommodate bicyclists.

Maryland

Maryland [47] has issued their recent rumble strips policy in 2011. This policy includes recommendation for SRS, CLRS, and TRS on different types of roadways. Rumble strips installation is not recommended on pavements with inadequate surface conditions.

Shoulder Rumble Strips

Shoulder rumble strips installation is recommended along inside and outside shoulder of all expressways and controlled access highway with posted limit of 40 mi/h or more. SRS should be installed on both inside and outside shoulders of other divided highways as well.

Centerline Rumble Strips

CLRS are recommended along undivided highways with 40 mi/h or greater posted speed limit and 10 feet or greater lane widths. In areas with high density of access points, CLRS should not be installed.

Considerations for Bicyclists

Along expressways sections where bicyclists are permitted, the accommodations of bicyclists are recommended. To accommodate bicyclists, rumble strips should be installed on roads with a 5 feet shoulder. A skip pattern with gaps of 12 feet in 60 feet cycle should be provided. Gaps for bicyclists should be discontinued where posted speed limit is 55 mi/h or greater except at intersections. Roadways with posted speed greater than 40 mi/h and less than 55 mi/h require minimum 4 feet clear shoulder width for rumble strips application. The length, width, and depth should be 5 inches, 6 inches, 3/8 inch respectively instead of 7 inches, 12 inches, and 1/2-5/8 inch to accommodate bicyclists.

Michigan

Shoulder Rumble Strips

Michigan [48] uses rumble strips in both median and outside shoulder on freeways. The minimum shoulder width is 4 feet. SRS are not used in freeway exit/entrance ramp shoulders. The dimensions of length, width, and depth are 14 inches, 7 inches, and 1/2-5/8 inch, respectively.

Michigan DOT uses rumble strips of 12 inches long, 7 inches wide, 3/8 inch deep with spacing of 5 inches on rural two-lane and four-lane highways. SRS are installed on roadways with at least 6 feet wide shoulder as shown in figure 15.

Centerline Rumble Strips

As part of a three-year statewide non-freeway rumble strips installation initiative. MDOT has installed CLRS on approximately 5400 miles of rural non-freeway high-speed highways with a posted speed limit of 55 mi/h and roadway width greater than 20 feet. Dimensions for CLRS used in Michigan are 16 inches long, 7 inches wide, and 3/8 inch deep, with spacing of 5 inches.

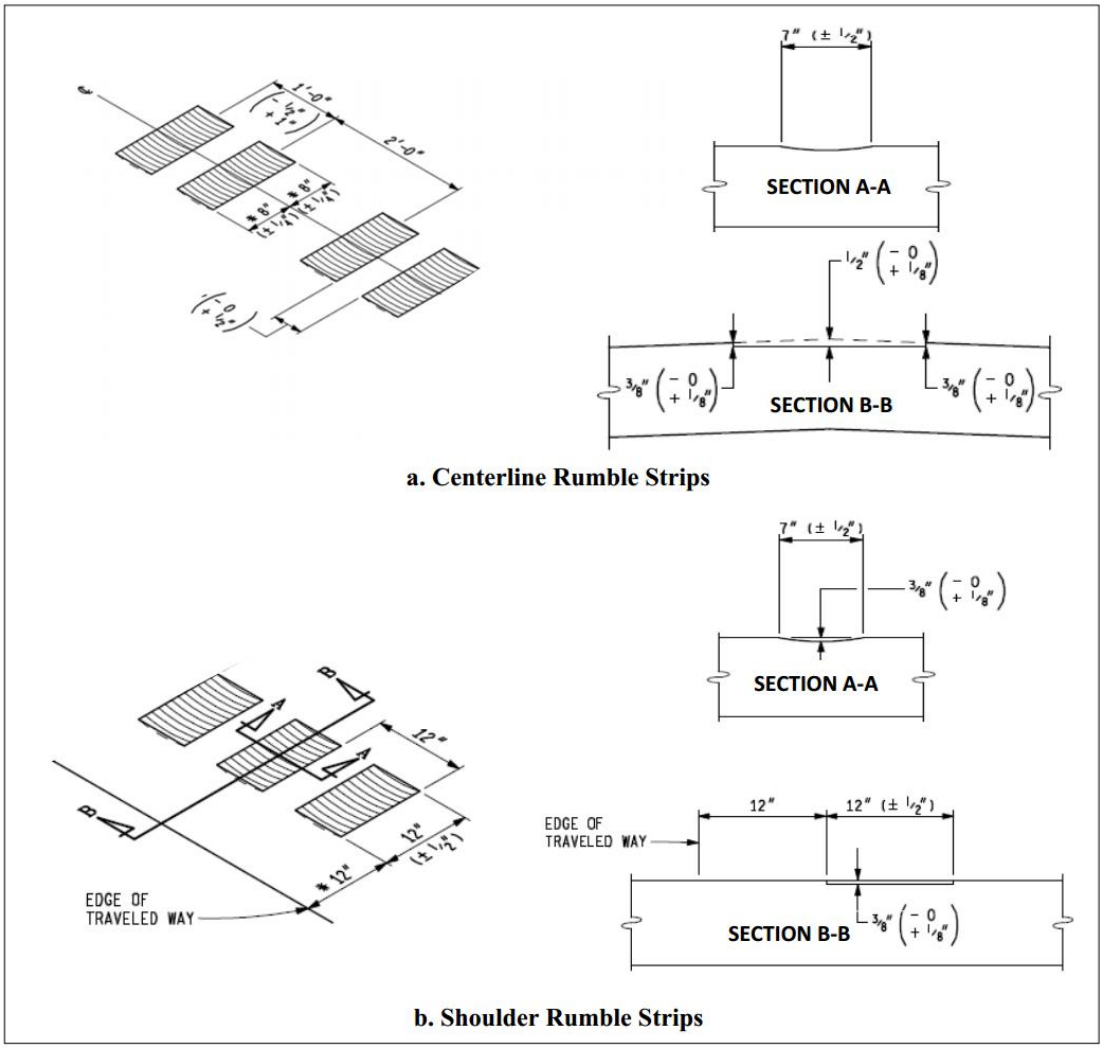

Figure 15: MDOT Rumble Strip Standards for Rural Non-Freeway Roadways [49]

Considerations for Other Roadway Users

MDOT has studied the impact of non-freeway rumble strips. [50] They conducted different surveys to get feedback from bicyclists and drivers. Impact of sound produced from strips was also studied using before/after crash analysis. The survey results recommended the use of 6 feet shoulders to accommodate bicyclists. Moreover, the majority of bicyclists responded positively on providing 12 feet gap in 60 feet cycle.

Noise

As mentioned earlier that rumble strips depth could affect the level of the generated noise,

different SRS and CLRS depths varying from 0.25-0.69 inch on non-freeway were examined in Michigan. [50] The sound level was measured from 50 feet away from the roadway. The study found that the depth of CLRS had the greatest effect on noise produced by test vehicles. Centerline rumble strips with depths of 0.5 inch or greater had a mean peak noise of 84.62 dBA, while CLRS with depths less than 0.5 inche produced 77.82 dBA. The study found, an average increase of 1.25 dBA per 0.0625 inch increase in rumble strips depth. Therefore, it was recommended to use rumble strips with depth between 0.25 inch to 0.5 inch to mitigate the level of noise for motorists' safety.

Minnesota

Minnesota DOT has recently updated their policy on rumble strips/stripes in 2012. In the new policy, they have changed different guidelines to accommodate bicyclists and motorcyclists.

Shoulder Rumble Strips

They strongly recommend to install SRS in all rural highways where posted speed limit is 55 mi/h or greater and shoulder width is equal to or greater than 4 feet.

SRS width of 16 inches is recommended on freeways and it can be reduced to 8-12 inches if the paved roadway width is limited.

Considerations for Other Roadway Users

According to the policy, 12 feet gap in each 60 feet cycle should be provided for routes with high bicyclists' traffic.

Montana

Montana DOT has updated their policy in 2012 to incorporate new research outcomes. [51] The new guideline included considerations for residential areas and bicyclists.

Shoulder Rumble Strips

According to the new guideline, all interstate, new construction, reconstruction, rehabilitation and overlay projects should include rumble strips on left and right shoulders. When guardrail

exists on roadway with shoulder less than 6 feet, the use of rumble strips should be evaluated before installation. For, all other types of roadways, where the shoulder width ≥ 4 feet, rumble strips should be installed on all new construction, reconstruction, rehabilitation, and overlay projects. These recommendations help to; alert errant drivers despite the potentially reduced effectiveness, reduce impacts to bicyclists by maximizing the width of shared lane, reduce incidental contact with rumble strips, and make drivers shy away from the shoulder because of placing rumble strips closer to the travel lanes, especially if the lanes are narrow.

On interstates, SRS should be installed on both shoulders. However, intermittent pattern is recommended on the right shoulder while a continuous pattern should be used in the left shoulder. It is also recommended to discontinue rumble strips in front of exit and entrance ramps.

For multi-lane divided national highway, primary and secondary routes, guidelines for interstate rumble strip installation should be adopted where shoulder width ≥4 feet, subject to restrictions within urban and residential areas. Justification for installing rumble strips where shoulders are between 1 and 4 feet needs to be documented in the Scope of Work of the project report. Rumble strips should not be provided where the shoulder width is less than 1 foot. Also, intermittent type rumble strips should be discontinued in front of guardrail, and if the shoulder width is less than 6 feet.

Centerline Rumble Strips

Centerline rumble strips are installed on undivided two-way roadway where Average Daily Traffic (ADT) =>750. Many factors control the decision of where to install centerline rumble strips; lane width, corridor vs. spot treatment, design speed, horizontal alignment, and motorcycles are among the factors discussed in the updated policy.

Consideration for Bicyclists

Dimensions of rumble strip shown in the MDT Detailed Drawings should be followed for most installations. Modifications to these dimensions might be warranted to accommodate different road users or to mitigate different factors. Where bicycle usage is a consideration, and the shoulder width is between 1 foot to 4 feet, it is recommend to install reduced lateral width rumble strips adjacent to the outside edge of the travel lane. When the shoulder width is > 4 feet,

offset from the edge of travel lane of 2 feet should be considered. A modified lateral width centerline rumble strip should be evaluated on narrow roads to reduce the adverse effect of vehicle/bicycle interaction, drivers tend to shy away from road centerlines where CLRS are installed. Rumble stripes use is not a standard practice in Montana, however, a justification must be provided if used. Depth of 3/8 inch is recommended to reduce the adverse effect of debris accumulation on rumble stripes.

Noise

Two options were recommended to reduce the noise effect in residential areas, 1) increasing the offset from the edge of the travel lane, and 2) using a quieter rumble strips by decreasing the depth from 5/8 inch to 3/8 inch. If decision is made to eliminate rumble strips in residential areas, rumble strips should be terminated 650 feet before nearby residents to provide a tolerable noise levels.

Nebraska

Shoulder Rumble Strips

Shoulder rumble strips are recommended for all interstate and expressways. Shoulder width should not be less than 6 feet wide for rumble strips installation. The typical dimensions are 12-16 inches long, 6 inches wide, 5/8 inch deep, and a spacing of 12 inches.

Edgeline Rumble Stripes

Edgeline rumble stripes are recommended on rural two lane highways where shoulder width is less than 6 feet. The minimum pavement width from shoulder to shoulder should be 28 feet with 12 feet lane and 2 feet shoulder on both direction. ADT should be more than 500 vpd and the posted speed limit should not be less than 50 mi/h. The strips should be 8 inches long, 7 inches wide, and 1/2 inch to 5/8 inch deep with the spacing of 12 inches.

Centerline Rumble strips

Nebraska DOT installs CLRS on all rural two-lane highways with 11 feet lane width (12 feet when ELRS is present). ADT should be of minimum 1500 vpd. Posted limit should be greater than 50 mi/h.

Eight inches CLRS should be placed with an offset of 2 inches from centerline on both sides. The other dimensions should be similar to ELRS.

New Hampshire

Shoulder Rumble Strips

For interstates and other limited access highways, the recommended dimensions for right side shoulder are 16 inches long, 7 inches wide, 1/2 inch deep with an offset of 30 inches. SRS should not be installed on bridge decks. Same dimensions are used on the left side shoulder with zero offset from the edgeline.

For other two-lane or undivided four-lane highways, SRS or ELRS both can be used. The recommended dimensions are 12 inches long, and 1/2 inch deep. Strips location shall be either 12 inches from the outside of the edgeline or directly beneath the edgeline.
Minimum 4 feet of clear area is recommended from the edge of pavement. If vertical obstructions such as guardrail or curbing are present, 5 feet clear area should be provided.

Centerline Rumble Strips

Centerline rumble strips should be installed on a roadway with 40 mi/h and pavement width of 28 feet. Also, the pavement should be in good condition and the minimum wearing course depth should be $\geq$ 1.25 inches. The length should be 12 inches with a depth of 1/2 inch. Strips should be placed under the pavement markings. CLRS should be discontinued at no passing zones, and intersections with left turn lanes.

Considerations for Bicyclists

Twelve feet gaps in 48 feet cycle should be provided for the bicyclists' safety and comfort.

North Carolina

Shoulder Rumble Strips

Rumble Strips should be installed on all interstate/freeways and expressways. Installation of rumble strips on rural multilane divided highways should be considered on a case by case basis.

The dimensions recommended to install strips should be 12-16 inches long, 7 inches wide, and 1/2 inch deep with a spacing of 12 inches. And the offset from the edgeline should be 6 inches.

Considerations for Bicyclists

Minimum of 4 feet usable shoulder should be provided for bicyclists. Also, the length of strips should be reduced to 8 inches based on engineering evaluation. Additionally, gaps should be provided with varying length of 6 or 12 feet on right shoulder on 30 or 60 feet cycle. No gaps are recommended on left shoulders.

North Dakota

Shoulder Rumble Strips

North Dakota installs SRS on interstates, divided highways (non-interstate) and in combination with CLRS on undivided highways.

On interstates, SRS are installed on both shoulders with the dimensions of 12 inches long, 7 plus or minus 0.5 inches wide, and 1/2 inch to 5/8 inch deep with a spacing of 12 inches on both shoulders, with a recommended offset of 6 inches. The lane width should be 12 feet with a 10 feet right shoulder and 4 feet left shoulder width.

Similar dimensions are used for divided highways (non-interstate). However, the shoulder requirements have not been provided in the standard drawing.

Shoulder rumble strips should be installed on both directions of undivided highways with shoulder width of 4 feet or greater. The strip dimensions and offset would be similar to the recommendation for interstates. SRS should be discontinued 100 feet ahead of right turn lanes.

The undivided highways with shoulder width less than 2 to 4 feet are installed with ELRS. Similar dimensions to the strips are used for ELRS.

Centerline Rumble Strips

Centerline rumble strips are installed on undivided highways with shoulder width ≥ 2 feet. Two different configurations are used for CLRS. When the shoulder width is 4 feet or greater, the recommended strip dimensions are 12 inches long, 7 plus or minus 0.5 inch wide, and 1/2 inch to 5/8 inch deep with alternating spacing of 12 inches and 24 inches. When the shoulder width is between 2 feet to 4 feet, the lengths of the strip are reduced to 8 inches and other dimensions remain the same. The strips are placed within the pavement markings.

Considerations for Bicyclists

To accommodate the bicyclists, 10 feet gaps are provided in 50 feet cycle on the undivided highways.

Utah

Utah has revised their rumble strips policy in 2007 to accommodate all roadway users.

Shoulder Rumble Strips

Shoulder rumble strips should be placed on both the left and right shoulders of all rural interstate divided highways. Consideration for rumble strips installation should be given on both shoulders of other non-interstate rural divided highways. Rumble strips are installed on undivided highways if speed limit is 45 mi/h or higher, considerable run-off-road crash experience, and with 4 feet minimum clear shoulders to accommodate bicyclists.

Centerline Rumble Strips

Centerline rumble strips should be installed where speed limit is 45 mi/h or higher and head on opposite direction sideswipe crashes are reported.

Considerations for Other Roadway Users

Rumble strips are not recommended where shoulders are used by bicyclists unless there is a minimum clear path of one foot from the rumble strip to the travel way, 4 feet from the rumble strip to the outside edge of paved shoulder, or 5 feet to adjacent guardrail, curb or other obstacle.

Washington

Shoulder Rumble Strips

Shoulder rumble strips are placed on both shoulders of rural divided highways. Washington applies the following criteria in evaluating the appropriateness of installing shoulder rumble strips on undivided highways.

- Use on rural roads only.
- Shoulder pavement is structurally adequate to support milled rumble strips.
- Speed limit is 45 mi/h or higher.
- At least 4 feet of usable shoulder between the rumble strips and outside edge of shoulder.
- Do not place shoulder rumble strips on downhill grades exceeding 4 percent for more than 500 feet in length along routes where bicyclists are frequently present.

Centerline Rumble Strips

Following criteria are considered in determining the appropriateness of centerline rumble strips:

- Crash history.
- Highway type, centerline rumble strips are mostly considered for rural roads.
- Structural adequacy of the roadway pavement.
- Width of roadway, Centerline rumble strips are not considered when the combined lane and shoulder widths in either direction are less than 12 feet.

Alberta, Canada

In Canada, Alberta was the first city to install rumble strips in 1991. Their guideline for rumble strips installation was last revised in 2012. Shoulder rumble strips are installed on all two-lane

and multi-lane highways where shoulder width is 4.6 feet or more. In case of bridges, rumble strips are installed 330 feet prior to the approach of the bridge and end 32 feet prior to deck. Rumble strips are not placed in bridge decks.
Centerline rumble strips are installed in all undivided paved highways. They are installed on both passing and no passing zone. Centerline rumble strips are discontinued 160 feet before of any intersection.

British Columbia, Canada

British Columbia has been using shoulder rumble strips since 1999. Rumble strips are used on rural roadways with high frequency of run-off the road crashes where posted speed limit is 45 mi/h or higher.

Shoulder Rumble Strips

It is not recommended installing rumble strips on roadways with shoulder depth less than 2 inches. If there is no bicycle traffic, minimum clear width between rumble strips and the edge of the shoulder should be 2.5 feet and where there is bicycle traffic, 5 feet clear width should be provided.
SRS are interrupted prior to driveways, intersections, ramps, shoulder constraints and wherever it is needed and required to allow cyclists to merge to the left of the SRS. Shoulder rumble strips are not installed on bridge decks and overpass structures and within 8 inches of expansion joint dams.

Table 1: Shoulder Rumble Strips in the U.S.

State	Length (in)	Width (in)	Depth (in)	Spacing (in)	Bicycle gap (ft)	Speed (mi/h)	Minimum Lane Width (ft)	Minimum Shoulder Width (ft.)	Noise Consideration	Types of Roadway	Comments
Alaska	16	7	0.50	12	12ft in 80 ft. cycle 12ft on 60 ft. cycle (high bicycle traffic)	50	-	6, 7 (w/ guardrail)	Y	R Freeway, U Freeway R two-lane , U two-lane	Do not install on pavements less than 2 inches thick
Alabama	12	7	0.625	12	10 ft. in 50 ft. cycle 12 ft. in 60 ft. cycle	45	n/a	2	N	U Freeway, R Freeway, U & R multilane divided, R multilane undivided, R two-lane	
Arizona	8 12	5	0.375-0.50	12	10 ft. in 40 ft. cycle	-	12	5, 6 (w/ guardrail)	Y	R Freeway, R multilane divided/undivided, R two-lane	
Arkansas	12	5	0.375	12	10 ft. in 60 ft. cycle	45	10	5 ft 4 inches	Y	R two-lane, U Two-lane, R multilane undivided, R Freeway, U Freeway	
California	6, 12	5±1	0.3125	12±2	Yes	35	-	5	Y	R Freeway, R two-lane	
Colorado	12	5	0.375	12	12 ft on 60 ft. cycle	-	-	6 (w/ guardrail)	Y	, R Freeway, U Freeway, R multilane divided/undivided, U & R two-lane	
Connecticut	16	7	0.50-0.625	12	n/a	n/a	n/a	3	N	U Freeway, R Freeway	
Delaware	16	7	0.375	12	12 ft. in 42 ft. cycle	-	11 (two-lane)	5 (two lane) 6	Y	U Freeway, R Freeway, U& R multilane divided/undivided, U & R two-lane	
Idaho	12 16	7	0.50-0.625	12	12 ft. 6 inches in 60 ft. cycle	45	12	2 4-8 >8	Y	R Freeway, R multilane divided, R two-lane	

State	Length (in)	Width (in)	Depth (in)	Spacing (in)	Bicycle gap (ft.)	Speed (mi/h)	Minimum Lane Width (ft.)	Minimum Shoulder Width (ft.)	Noise Consideration	Types of Roadway	Comments
Indiana	16	7	0.50	12	20 ft. in 100 ft. cycle	50	-	2 (Edgeline) 4 (Bicyclists)	N	U Freeway, R Freeway, R multilane undivided	Do not install in urban areas
Kentucky	16	7	0.50± 0.125	12	No Provision	45	11	5, 6 (w/ guardrail)	Y	U Freeway, R Freeway, U& R multilane divided/undivided, U & R two-lane	
Maine	16	7	0.5± 0.06	24	12 ft. in 60 ft. cycle	45	11	4	Y	U Freeway, R Freeway, R two-lane	Min. 1 ¼ inches surface pavement
Massachusetts	16	7	0.5	12	16 ft. in 64 ft. cycle	40	-	2 (I) 8 (NI)	Y	U Freeway, R Freeway, U & R multilane divided/undivided, R two-lane	Do not install in intersection and bridge decks
Michigan	12	7	0.375± 0.125	5	12 ft. in 60 ft. cycle	-	-	6	Y	U Freeway, R Freeway, R two-lane	
Minnesota	16 (I) 12(NI)	7±0.50	0.375-0.50	12	12 ft. in 60 ft. cycle	55	-	4	Y	U Freeway, R Freeway, U & R multilane divided/undivided, R two-lane	
Missouri	16	5	0.437± 0.0625	12	12 ft. in 60 ft. cycle	50	12	5 6(w/ guardrail)	Y	U Freeway, R Freeway, U & R multilane divided/undivided, R two-lane	Do not install in intersections, driveways, or residential areas
Montana	-	6	0.375-0.625	-	Y	-	-	4	Y	R Freeway, U Freeway, R two-lane	

State	Length (in)	Width (in)	Depth (in)	Spacing (in)	Bicycle gap (ft.)	Speed (mi/h)	Minimum Lane Width (ft.)	Minimum Shoulder Width (ft.)	Noise Consideration	Types of Roadway	Comments
Nevada	16	6	0.5	12	12 ft. in 60 ft. cycle	-	-	4	Y	R Freeway, R multilane divided/undivided, R Two-lane	
New Hampshire	16 (I) 12(NI)	7 8	0.5,	30, 12	12 ft. in 60 ft. cycle	40	-	4(Clear width), 5(Clear width,w/ guardrail)	Y	U Freeway, R Freeway, U two-lane, R two-lane	
New Mexico	16	7, 12 (if no Bicyclists)	0.50	12	Yes	50	-	4, 5 (w/ guardrail), 6 (SRS & CLRS)	Y	R Freeway, R two-lane	
New Jersey	16	7	0.50	12	No provision	n/a	n/a	6	-	U Freeway, R Freeway	
Pennsylvania	16	5±0.5	0.375± 0.0675	12	12 ft. in 60 ft. cycle	55	11	6	Y	U & R Freeway, U & R multilane divided/undivided, U & R two lane	Do not install at intersection and bridge decks
South Carolina	16	7	0.50	12	12 ft. in 60 ft. cycle	45	12	6	N	U Freeway, R Freeway, R Multilane undivided, R two-lane	
South Dakota	12	7±0.5	0.50-0.75	12	Continuous (I), 12 ft. in 52 ft. cycle (NI)	50	12	4	N	R Freeway, R multilane undivided, R two-lane	Should not be placed in ramps and gore areas.
Tennessee	16	7±0.5	0.375-0.5	-	10 ft. in 40 ft. cycle	-	-	-	Y	R Freeway, U Freeway ,R Two-lane, U Two-lane	

State	Length (in)	Width (in)	Depth (in)	Spacing (in)	Bicycle gap (ft.)	Speed (mi/h)	Minimum Lane Width (ft.)	Minimum Shoulder Width (ft.)	Noise Consideration	Types of Roadway	Comments
Utah	12		0.625-0.75	12	12 ft. in 60 ft. cycle	45	12	6 7 (w/ guardrail)	-	U & R Freeway, R multilane divided/undivided, R two lane	
Virginia	16	7	0.5	12	12 ft. in 60 ft. cycle	45	11	6,7**	-	R Freeway	
Washington	16 12**	7±0.5 5±0.5	0.5-0.625, 0.375	12	12 ft. in 60 ft. cycle	45	-	6 7 (w/ guardrail)	-	U & R Freeway, R multilane divided/undivided, R two-lane	
Wisconsin	16	7	0.5-0.625	10±1	12 ft. in 60 ft. cycle	-	-	6	N	U Freeway, R Freeway, R two-lane	
Wyoming	16	7	0.5-0.625(I) 0.375-0.5 (NI)	12	12 ft. in 60 ft. cycle	45	n/a	6	N	R Freeway, R multilane undivided, R Two-lane	

* Some States are still updating their guidelines, and, for some others, they don't have all the specifications.
** High bicycle traffic, residential areas.
Y= Yes
N= No
I= Interstate
NI= Non-Interstate

Table 2: Centerline Rumble Strips in the U.S.

States	Length (in)	Width (in)	Depth (in)	Spacing (in)	Motorcyclists Consideration	ADT (vpd)	Speed (mi/h)	Min. Lane Width (ft.)	Min. Shoulder width (ft.)	Roadway type	SRS and CLRS Combination	Advance Warning Sign	Comments
Alaska	12	7	0.375	12	Y	-	45	14 (Combined)		Rural two-lane	-	N	Not installed in urban areas
Arizona	5,8,12	6.50	0.50	12	-	-	-	-	-	R multilane undivided, R two-lane	-	-	
Arkansas	16	5	0.375	-	N	-	45	10	-	R two-lane	N	N	NP
California	6,12	5±1	0.3125 ±0.062 5	12±2	N	-	35	-	-	Rural two-lane	-	-	Breaks in intersection or commercial driveway with more than 500 Veh
Colorado	12	6.50	0.375	12	N	-	-	-	-	R multilane undivided			NP & P
Connecticut	12±0.5	7±0.5	0.375, 0.50	24±0.5	N	2000	45	13 (Combined)		R two-lane	N	N	Continues in NP, breaks in P and Intersection
Idaho	12	7±0.5	0.50 0.625	12±0.5	Y	500	45	12	-	R multilane undivided, R two-lane	-	N	Breaks in P
Indiana	16	7±0.5	0.50	12 and 24 alternatin g	N	-	50	10	2	R multilane undivided, R two-lane	N	N	
Kansas	12	6.5	0.50	12 and 24 alternatin g	N	3000	50	-	-	R two-lane	Y	N	
Kentucky	12	7-7.5	0.50 0.625	24	N	-	45	11	1.5	U two-lane , R two-lane	Y	N	

States	Length (in)	Width (in)	Depth (in)	Spacing (in)	Motorcyclists Consideration	ADT (vpd)	Speed (mi/h)	Min. Lane Width (ft.)	Min. Shoulder width (ft.)	Roadway type	SRS and CLRS Combination	Advance Warning Sign	Comments
Maine	12	7	0.50± 0.06	24	Y	3000	-	11	-	R two-lane	Y	Y	
Michigan	16	7	0.375	5	-	-	-	-	-	R two-lane	Y	Y	
Minnesota	12-16	7±0.50	0.375-0.50	12	-	-	55	-	-	R two-lane	-	-	
Missouri	12		0.50	-	-	-		10	-	-	-	-	
Montana	-	-	-	-	N	750	45	-	-	R two-lane	Y	N	
Nevada	-	-	-	-	N	-	-	-	2	U multilane undivided, R multilane undivided, R two-lane	Y	N	
New Hampshire	12	7	0.375-0.50	12	N	-	40	14 (Combined)		R two-lane	Y	N	Continues through P
New Mexico	-	-	-	-	N	-	50	14 (Combined)		R two-lane	Y	N	
New Jersey	-	-	-	-	-	-	35	11		R two-lane	N	N	
Oregon	16	7	0.50	12	N	-	-	-	-	R multilane undivided, R two-lane	Y	N	
Pennsylvania	16	7±0.50	0.50 ±0.0625	24	N	1500	-	10	-	R multilane undivided, U multilane undivided, U two-lane, R two-lane	Y	N	

States	Length (in)	Width (in)	Depth (in)	Spacing (in)	Motorcyclists Consideration	ADT (vpd)	Speed (mi/h)	Min. Lane Width (ft.)	Min. Shoulder width (ft.)	Roadway type	SRS and CLRS Combination	Advance Warning Sign	Comments
South Carolina	12	7	0.375-0.50	-	N	500	45	12	-	Multilane Highways, U two-lane	Y	N	
South Dakota	12	5±0.50	0.375-0.50	12	N	-	50	12	4	R two-lane	N	N	
Utah	12	8	0.625-0.75	12	-	-	45	-	-	R multilane undivided, R two-lane	-		
Virginia	14	7	0.5	12	-	-	45	11	-	U multilane undivided, R multilane undivided, R two-lane	-	-	
Washington	12	7±0.50	0.50-0.675	12	N	-	45	12 (Combined)		R multilane undivided, R two-lane	Y	N	Breaks on bridge decks
Wyoming	12	7.5	0.50-0.675	14.5	N	-	45	14 (Combined)		R two-lane	N	N	

* Some States are still updating their guidelines, and, for some others, they don't have all the specifications.
Y= Yes
N= No
NP = No-passing Zone
P= Passing Zone

SAFETY EFFECTIVENESS OF RUMBLE STRIPS/STRIPS

Rumble Strips

The safety effectiveness of shoulder rumble strips was evaluated in many states. NCHRP Report 641 [31] indicated that shoulder rumble strips can reduce Single Vehicle Run-Off the Road (SVROR) crashes by 10 to 80 percent with an average reduction of 36 percent. The report showed also a reduction of 21 percent of total crashes. In Pennsylvania, Massachusetts, Washington, Kansas, SVROR crashes were reduced by 60, 42, 18, and 3 percent respectively. In addition to shoulder rumble strips, centerline rumble strips were also determined to be very effective in reducing head-on crashes. The percentage of head-on crashes was reduced by 34 to 95 percent with an average of 65 percent due to centerline rumble strip.

Briese (2006) [52] examined the effect of speed, lateral placement, and centerline incursion on CLRS. The study analyzed data from 109 miles of treated versus 215 miles of untreated rural two lane highways in Minnesota. The study reported a decrease of 25 percent of fatal crashes on roadways with CLRS. It was concluded that CLRS do not affect travel speed and have a little effect on lateral vehicle position.

Torbic et. al. (2010) [53] reported 36 percent crashes reduction in SRS on 257 rural two-lane roadway segments. The safety effectiveness of CLRS was also estimated; the study showed a reduction of 40 percent and 64 percent in fatal and injury crashes on urban two-lane roads, respectively. In table 3, in rural two-lane roads and urban freeway, the reductions were estimated 8 percent and 16 percent in fatal and injury crashes respectively.

Olson [54] concluded that lane and road departure crashes were respectively reduced by 12 percent, 63.3 percent, and 66 percent due to using SRS, SRS and CLRS, and composite rumble strips. It is worth mentioning that SRS and CLRS means that the CLRS were added on roadways with SRS, while composite rumble strips means that both SRS and CLRS were installed at the same time. The SVROR crashes was reduced in a huge margin too. For, SVROR crashes, the occurrence of SVROR had been reduced respectively by 40.4 percent, 61.4 percent, and 61.6 percent for SRS, SRS and CLRS, and composite rumble strips.

Outcalt (2001) [55] reported a reduction of 34 percent and 36.5 percent in head on crashes and opposite sideswipe crashes per million vehicles, respectively. It also reported a considerable increase in ADT after installing rumble strips.

Hirasawa, (2005) [56] conducted an observational before-after analysis on 69.5 miles of CLRS; a reduction of 55.2 percent in head on crashes was reported. Also, the study compared the impact of CLRS on noise, vibration and driver perception by varying CLRS dimensions. Greater noise inside the test vehicle was observed for the higher depth groove. Vibration measurement also showed similar result as noise study. For deeper grooves, higher vibrations were measured. With the increase of speed, the noise and vibration also increase. The study concluded that drivers received higher degree of warning from rumble strips. Among the different test sections, 12 mm (0.47 inch) and 15 mm (0.59 inch) strips were found to provide the highest degree of warning to drivers.

In table 4, effectiveness of CLRS from different states has been summarized. California experienced 90 percent reduction in fatal head on crashes and 42 percent reduction in total head-on crashes. Kansas reported 81 percent, 78 percent reduction in head-on and sideswipe crashes, respectively.

Rumble Stripes

In 2006, a study was conducted by Lindy and Narci,[40] to evaluate rumble stripes in Alabama, taking into account service life, life cycle costs, and wet-night visibility. The dimensions of rumble stripe used in Alabama were length of 16 inches, width of 7 inches, depth of 0.50 to 0.625 inch, and a spacing of 12 inches. Wet retroreflectivity was found to be acceptable, even after many years of service. Based on this study, it was recommended that rumble stripes should be implemented in future projects where paved shoulders were constructed and where bicyclist issues and FHWA technical requirements could be met.

In 2009, Hallmark, et al. [41, 42] evaluated edge rumble stripes on low traffic volume rural roads in Iowa. The rumble stripes were milled in, with dimensions of 4 to 6 inches in width and 0.625 inch depth. Results showed that the average vehicle lane position moved closer to the center of the lane after the installation of rumble stripes. Finally, qualitative assessment of

pavement marking conditions two years after installation was performed; the results showed that the regular pavement markings on the pavement surface were flushed away by snowplows, while those on rumble strips remained. The study concluded that rumble stripes are successful in preserving the pavement marking and improving visibility. The study recommended that narrow rumble stripes could be an effective alternative on roads with no or narrow shoulders.

In 2012, Mitkey, et al. [43] examined the retroreflectivity durability of rumble stripes versus painted edgelines. A two lane section of divided highway in Indiana before and after winter season was used to compare the two. The dimensions of rumble stripes used were 16 inches long, 7.5 inches wide, 0.5 inch deep with 12 inch spacing. Results from qualitative and quantitative analyses showed that rumble stripes are effective in increasing the night and wet-night time visibility of pavement markings along the rural roadways. The durability of pavement markings was also increased due to rumble stripes. After one winter season, the coefficient of retroreflectivity for rumble stripes exceeded the painted edgelines by 95 percent for white and 80 percent for yellow under dry conditions. The conclusion drawn by the study was that rumble stripes provide an increase in nighttime visibility in dry and wet conditions. Also, they improve the durability of the pavement marking.

Combination of SRS and CLRS

Many states are currently using SRS and CLRS in combination to provide increase safety for motorists. A combination of SRS and CLRS can reduce lane and road departure crashes significantly. Olson (2013), conducted a study in Washington to evaluate the performance of SRS and CLRS installed in combination. [54] The evaluation was conducted by varying different parameters and conditions for five different scenarios including; locations where SRS were installed, locations with composite SRS and CLRS, locations where SRS had been initially installed and CLRS were added at a later time, locations where CLRS had initially been installed and SRS were added at a later point in time, locations where there were no rumble strips in the before period and both CLRS and SRS were installed in the after period. The second scenario showed a 63.3 percent reduction in lane and road departure crashes and a 79.4 percent reduction on asleep or fatigued drivers related at lower speeds. With posted speed of 50 mi/h, a 49.2 percent reduction was noted; while, where CLRS were installed after SRS, a 44.6 percent

reduction in crashes due to lane and road departures. The composite sections, where SRS and CLRS were both newly installed, a 66 percent reduction in lane and road departure crashes was reported and 56 percent of fatal and serious injury crashes were reduced. The combined use of both type rumble strips was also effective at different levels of AADT.

Table 3: Safety Effectiveness of SRS on Four Crash Types

Roadway Type	State	Crash Type							
		Changes in Crash frequency from Before to After Rumble strip Installation (%)							
		Total Target Crashes		Fatal Injury		Single Vehicle Run off Road		Single Vehicle Run off Road-Fatal Injury	
		Estimate	SE[1]	Estimate	SE[1]	Estimate	SE[1]	Estimate	SE[1]
Urban Freeway	**Pennsylvania**	-1.4	5.7	-16.0	7.2	-5.8	7.3	-7.4	9.9
Rural Freeway	**Combined**	7.0	3.9	-63.9	5.9	-9.7	5.2	-17.1	7.3
	Missouri	7.9	4.1	-5.8	6.4	-7.9	5.7	-15.6	8.2
	Pennsylvania	0.3	11.8	-12.6	14.6	-17.7	12.3	-23.2	15.7
Rural multilane divided highways	**Combined**	18.1	7.8	-10.2	10.2	40.0	12.4	-2.6	13.5
	Minnesota	10.2	14.7	-22.2	19.6	38.4	26.6	-10.3	28.6
	Missouri	22.0	9.5	-5.2	12.3	44.8	14.8	.2	15.8
	Pennsylvania	-13.3	35.6	-40.1	42.5	-25.5	37.4	-19.9	56.9
Rural two-lane roads	**Combined**	5.9	5.7	-8.0	8.0	-16.2	8.1	-36.4	9.7
	Minnesota	14.4	8.0	5.1	12.7	10.7	17.1	-32.4	17.6
	Missouri	40.5	18.0	-19.2	21.8	16.9	21.8	-44.6	23.2
	Pennsylvania	-24.4	8.6	-18.0	11.6	-43.6	9.1	-36.7	13.3

(Source: Torbic, Darren J. et.al) (2010) [53]

Table 4: Safety Effectiveness of CLRS

State	Study	Statistical method	Type of Crash Studies	Crash reduction
Arizona	AECOM (2008)	Comparison Group	Fatal and serious injury cross-over	61.0%
	Kar and Weeks (2009)	Naïve Before-and-After	Fatal and serious injury cross-over	56.0%
California	Fitspatric et al. (2000)	Naïve Before-and-After	Fatal head-on	90.0%
			Total head- on	42.0%
	Persaud et al. (2003)	Empirical Bayes	Cross-over	12.0%
			All types	14.0%
Colorado	Outcalt (2001)	Naïve Before-and-After	Head-on	34.0%
			Sideswipe	36.5%
	Persaud et al. (2003)	Empirical bayes	Cross-over	31.0%
			All types	11.0%
Delaware	Delaware DOT (2003)	Naïve Before-and-After	Head-on	95.0%
			Drove left to the center	60.0%
			PDO	Increase 13%
			Injury	Increase 4%
			All types	8.0%
	Persaud et al. (2003)	Empirical Bayes	Cross-over	81.0%
			All types	23.0%
Kansas	Karkle et. al (2009)	Naïve Before-and-After	Fatal Head-on	80.0%
			Head-on	81.0%
			Sideswipe	78.0%
			Cross-over	80.0%
			Fatal and serious injury cross-over	59.0%
		Empirical Bayes	Cross-over	85.0%
			All types	33.0%

State	Study	Statistical method	Type of Crash Studies	Crash reduction
Maine	Unpublished Maine DOT	Naïve Before-and-After	Head-on	91.7%
			ROR	28.9%
Maryland	Persaud et al. (2003)	Empirical Bayes	All types	19.0%
Massachusetts	Noyce and Elango (2004	Comparison Group	Several	Inconclusive
Minnesota	Persaud et al. (2003)	Empirical Bayes	Cross-over	Increase 12%
			All types	0.0%
	Briese (2006)	Cross-Sectional Comparison	Cross-over	43%
			All types	42%
			Cross-over- Fatal and severe injury	Increase 13%
			All types- Fatal and severe injury	73.0%
	Knapp and Schimdt (2009)	Cross-Sectional Comparison	Cross-over- Fatal and severe injury	47.0%
			All types- Fatal and severe injury	40.0%
	Torbic et al. (2009)	Empirical Bayes	All types	11.1%
			Fatal and Injury	21.8%
			Cross-over	48.9%
			Fatal and injury cross-over	44.7%
Missouri	Unpublished Missouri DOT	Naïve Before-and-After	Head-on	29.0%
			Sideswipe	61.0%
		Empirical Bayes	Head-on	53.0%
			Sideswipe	62.0%
Nebraska	Unpublished Missouri DOT	Naïve Before-and-After	Cross-over	64.0%
Oregon	Monsere (2002)	Naïve Before-and-After	Cross-over	69.5%
		Comparison Group	Cross-over	79.6%

State	Study	Statistical method	Type of Crash Studies	Crash reduction
	Persaud et al. (2003)	Empirical Bayes	All types	46.0%
Pennsylvania	Galenabiewski et al (2008)	Naïve Before-and-After	Cross-over	48.0%
	Torbic et al. (2009)	Empirical Bayes	All types	1.6%
			Fatal and Injury	6.2%
			Cross-over	25.8%
			Fatal and injury cross-over	44.4%
Washington	Persaud et al. (2003)	Empirical Bayes	Cross over	21.0%
			All types	25.0%
	Torbic et al. (2009)	Empirical Bayes	All types	Increase 2.3 %
			Fatal and Injury	Increase 4.1%
			Cross-over	35.4
			Fatal and injury cross-over	35.4

(Source: Karkle, Daniel E. et.al.) (2011) [57]

ISSUES ASSOCIATED WITH RUMBLE STRIPS

As discussed earlier, rumble strips are used by many states as a relatively low cost proven safety countermeasure to reduce or prevent lane departure crashes. Although the advantages of rumble strips were generally found to outweigh the disadvantages, several issues and concerns have been identified regarding the implementation of rumble strips; noise, maintenance, and the adverse effects on bicyclists and motorcyclists are among the most recognized concerns. Many DOTs are still updating their rumble strips policies to accommodate all roadway users. State DOTs which had already been using their own guidelines are now moving forward to accommodate non-conventional vehicles and nearby residents. The following sections discuss provisions State DOTs included in their new rumble policies to accommodate all road users.

Impact on Bicyclists

Shoulder rumble strips could be an issue for bicyclists as most of them ride their bicycles on shoulders. When there is not enough shoulder width provided, bicyclists may have to ride over the rumble strips which can impose a great risk on them. The vibrations from rumble strips can lead bicyclists to lose control of their bicycles. Sometimes, they might have to move from the lane to the shoulder or vice versa, in that case they also have to cross the rumble strips. There are many agencies working on finding suitable design to accommodate bicyclists. Some of the steps taken include providing gaps after a certain length so that bicyclists can move safely from shoulder to lanes. Various State DOTs and transportation agencies used different spacing, for example 12 feet in every 48 feet, 10 feet in every 30 feet, and 20 feet in every 60 feet. Another measure taken is reducing the depth of rumble strips grooves which generates less vibrations and therefore will have a milder effect on bicyclists' rideability, controllability and comfort on rumble strips. Many State DOTs are using SRS groove depth of 0.375 inch where high bicyclists' traffic is expected instead of the commonly used 0.5 inch on other roadways. Also, shoulder rumble strips are not recommended by many states on narrow shoulders of less than 6 feet. In 2001, Outcalt [(20)] did a study for Colorado DOT to design bicycle friendly rumble strips. After experimenting with various dimensions and patterns, they recommended to use a groove depth of 0.375 inch and to provide 12 feet gaps in every 60 feet. The study also concluded that the groove depth of 0.375 inch can produce enough vibration and noise to effectively alert drivers. To reduce the risk of bicyclists running over SRS, Colorado DOT provides advance warning signs.

Impact on Motorcyclists

Centerline rumble strips has long been thought to be a concern for motorcyclists' controllability, field experiments examining the interaction between motorcycles and rumble strips concluded that rumble strips add no measurable risk to motorcyclists. A detailed field study by Miller [(21)] for the Minnesota DOT in 2008 concluded that CLRS do not pose any threat to motorcycles or three wheeled motorcycles. No unusual behaviors were found when 32 motorcyclists traversed rumble strips in a closed course. The study also found that for most of motorcyclists, the first encounter of rumble strips were over intimidating due to inexperience on riding over rumble

strips. It was reported that there are very few reported crashes due to the rumble strips; and in most of the cases, the drivers were inexperienced. Other study conducted by Pennsylvania and Washington DOTs [14, 15, 28] did not find any direct threat for motorcyclists due to CLRS.

Noise

Although the purpose of using rumble strips is to warn drivers through audible sound and vibrations, noise generated by rumble strips could disturb nearby residents. Noise is a major concern reported by several transportation agencies because of the frequent complaints received from nearby residents. Several studies have been performed to develop a rumble strips design that generate acceptable level of noise without sacrificing benefits to motorists. A study done by Minnesota DOT [58] reported, at 50 feet distance, noise level produced by a vehicle driving over a rumble strips is comparable to a truck passing by on a standard, non-rumbled surface. At 300 feet from the road, the average sound level, was found to be equivalent to the sound produced during a normal conversation. Another study conducted by Michigan DOT [59] used a 2005 Ford F-350 at 70 mi/h speed to measure the noise at different distances. The study reported a 16.2 and 25 dBA increase over the average daytime freeway noise level at 95 feet and 50 feet distances from the roadway respectively. In 2008, another study [12] was conducted to evaluate the effectiveness and quietness of football and rectangular shaped rumble strips. It was concluded that football shaped rumble strips can be an effective alternative to the rectangular shaped rumble strips. Additionally, a survey, which was part of this study, showed that bicyclists preferred the football shaped rumble strips over the rectangular shaped. Nowadays, DOTs are using alternative design (e.g. shallow depth, and shorter length) to reduce noise. In addition, DOTs have limited use of rumble strips near residential areas due to noise complaints from residents. Rumble strips are warranted in urban/residential areas if only specific locations have frequent crash history.

DIMENSIONS

Various agencies use different dimensions for their rumble strips. Since the publication of the NCHRP guideline, [31] most of agencies have modified or are in the process of updating their policies. According to table 1, the lengths of shoulder rumble strips vary from 6 to 16 inches. Some agencies use the same length for all types of roadway regardless of locations and users.

Whereas, other agencies vary the length of SRS based on roadway types, and volumes of bicyclists. The most common lengths used by most agencies for SRS are 12 inches and 16 inches. As indicated in table 2, for CLRS, a longer length is used compared to SRS, up to 24 inches. However, similar to SRS, 12 inches and 16 inches are the most common length used for CLRS. For the width of the strips, most agencies use either 5 inches or 7 inches. There are few agencies that use different widths of 6 and 12 inches. Previously, agencies used 0.5 inch or more of groove depth which produced loud sound. But, after various studies, researchers have found that 0.375 inch groove depth can produce enough auditory and vibratory sound to alert drivers. There are still a few agencies that use 0.5 inch or 0.625 inch groove for their rumble strips. Usually, same depths are used for both SRS and CLRS.

SHAPES

A study was performed by the Kansas DOT [(12)] to compare the football and rectangular shaped rumble strips to determine which one is the most efficient and quieter while ensuring safety. Several tests were done to compare these two shapes of strips. They were examined in order to find out how long it takes for water and debris to be removed from the grooves. Football and rectangle shape rumble strips both performed similarly on water and debris accumulation/removal. Another test was designed to measure the noise and vibration levels generated inside vehicles by the two shapes, the study indicated that there is no significant difference between the two rumble strips shapes. However, it was concluded from the bicyclist surveyed that football shaped rumble strips are more preferred.

CHAPTER 3- SURVEYS

In order to support the development of an effective shoulder and centerline rumble strips/stripes policy to accommodate all road users in Wyoming, several survey questionnaires have been conducted to gather opinions and feedbacks from bicyclists and nearby residents in Wyoming, WYDOT engineers, and other State DOTs in the U.S. This chapter presents the design, administration, and results of a survey-based studies concentrating on understanding other road users' preference on the increase of using rumble strips in the State of Wyoming. As shown in figure 16, 30 State DOTs responded to the survey questionnaire, 11 State DOTs provided additional information on their rumble strips/stripes guideline and provisions to accommodate other road users and nearby residents. A total of 45 engineers from WYDOT participated in this study through an online survey. A total of 57 bicyclists, 5 motorcyclists, and 50 nearby residents provided their feedback through different survey approaches; mail out, interactive door to door, and online questionnaire as shown in figure 17.

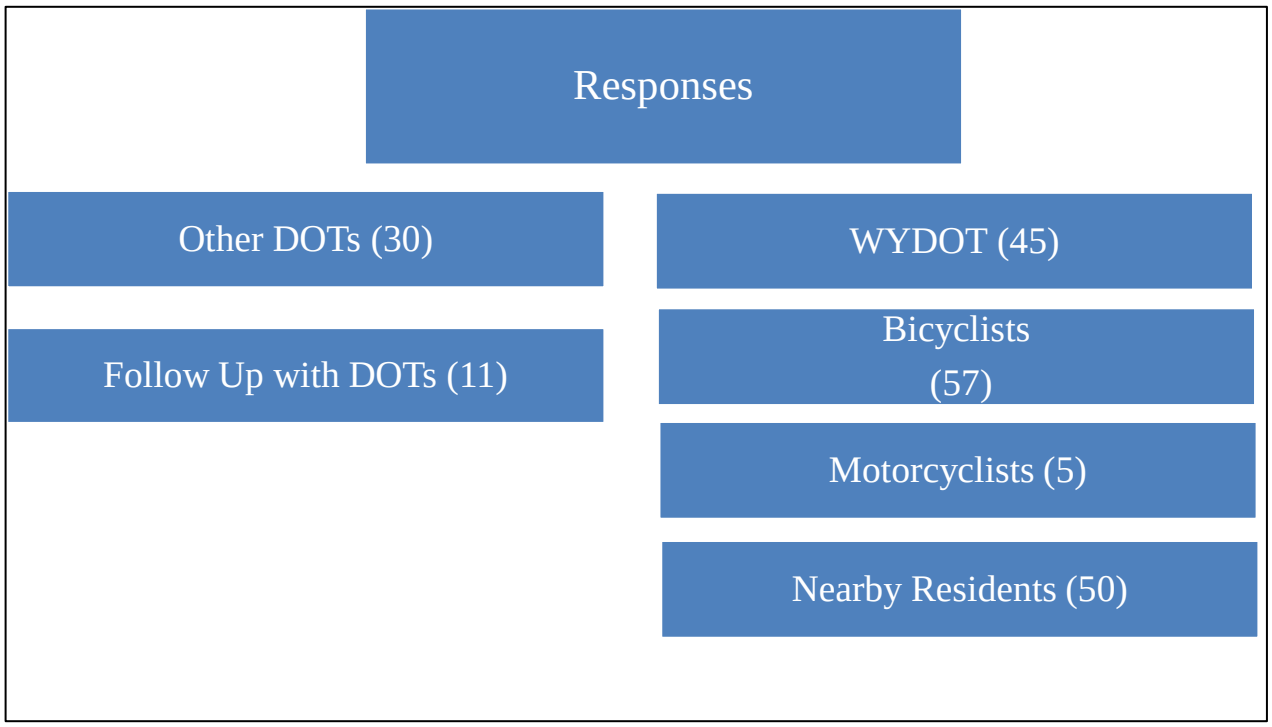

Figure 16: Survey Responses from DOTs and Other Road Users

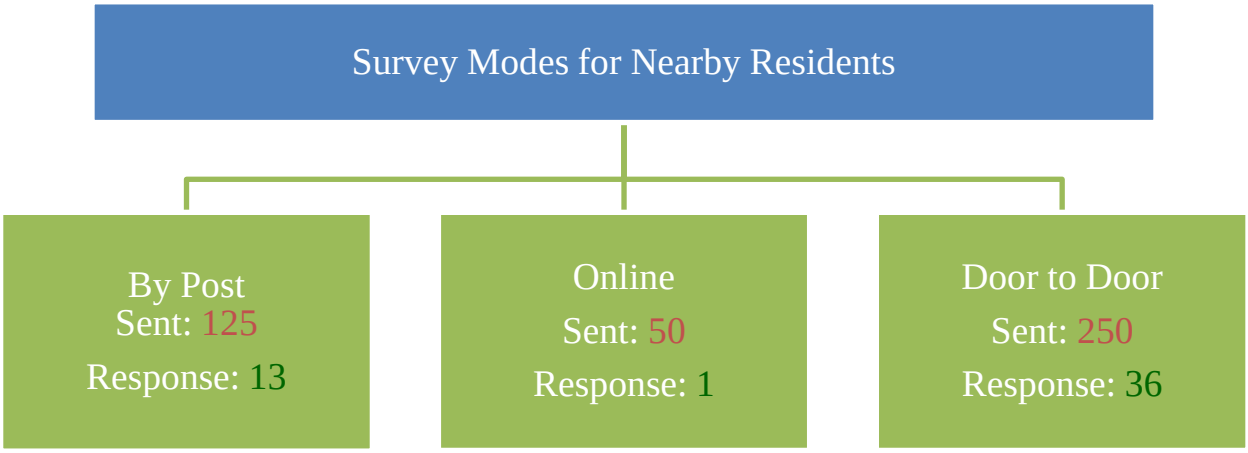

Figure 17: Survey Mode for Nearby Residents

DOTS SURVEY

As mentioned earlier, a survey was developed as part of this research and disseminated to States' DOTs to collect an up to-date information about their policies and practices for installing and maintaining rumble strips/stripes. The online survey was distributed to the 50 U.S. State DOTs, 31 State DOTs have responded to the online questionnaire; however, two State DOTs did not fully complete the survey and hence were eliminated from the analysis. The survey asked questions about existing and evolving policies and guidelines governing the design and application of rumble strips while accommodating other road users. A copy of the survey questionnaire is provided in appendix 1.

The survey results showed that many DOTs are still updating their rumble strips policies. State DOTs which had already been using their own guidelines are now moving forward to accommodate the non-conventional vehicles and nearby residents. The survey results showed that about 64 percent of the states are following the NCHRP Report 641 guideline, either strictly or with some modifications to suit their regions. Roadway classification and land use play a main role in the decision of installing rumble strips in general; states vary in their criteria of implementing rumble strips based on the type of area. It remains clear that shoulder rumble strips are the most used out of the three types of rumble strips. Rumble strips are installed mostly on rural roadways since they possess fewer constraints on installation criteria. Only 45 percent of the State DOTs respondents have evaluated rumble strips in their states and 21 percent are in the

process of evaluating their safety effectiveness. The use of the combined SRS and CLRS is not adopted by all the states, only 55 percent of the states are using both types in combination. Although, in the NCHRP report 641, it was recommended to accommodate all roadway users in the rumble strips policy, 14 percent of the DOTs stated that their policies do not have any provisions for bicyclists; whereas, 45 percent of the State DOTs do not consider the noise problem when installing rumble strips. Nevertheless, most of the State DOTs commented that they try to avoid installing rumble strips in urban areas to reduce nearby residents' complaints. From the review of the literature and the survey responses, it was found that 36 states have made provisions to accommodate bicyclists; while only 3 states (Florida, Idaho, and Maine) attempted to accommodate motorcyclists. Idaho DOT uses centerline rumble strips only in no-passing zones. Maine DOT provides skip pattern in their rumble strips to facilitate motorcycle lane changes. According to the survey results, the governing criteria ranked by DOTs when a roadway is considered for installing rumble strips are in the following order; area type (urban vs. rural), guardrail, pavement type, pavement thickness, bicycle traffic, motorcyclists, noise, nearby residents.

Rumble Strips/Stripes Implementation

In tables 5 and 6 the use of different types of rumble strips/stripes on different types of roadways has been listed. This list has been prepared based on the survey responses collected from different DOTs. Tables 5 and 6 provide information about shoulder rumble strips, centerlines rumble stripes.

According to the results shown in table 5, it can be seen that all types of rumble strips are mostly applied for rural two-lane highways in all states, respectively at 79 and 72 percent for SRS and CLRS. However, for the other types of roads, the proportions of rumble strips' applications differ. The percentage of shoulder rumble strips application varies from 24 percent for urban two-lane highway to 96 percent for rural freeways. Centerline rumble strips are applied to 21 percent of the states for rural multilane undivided highways whereas 79 percent of the states use SRS on rural multilane undivided highways.

It is worth mentioning that bicyclists are not allowed on rural freeways on most states and hence the application of continues shoulder rumble strips is the standard on rural freeways.

Figure 18 shows that the main conditions which may prevent the installation of rumble strips are the area type, presence of guardrail, pavement type, asphalt thickness and condition, bicycle traffic, motorcyclists, noise, and nearby residents. Ninety-seven percent of the respondents stated that area type is the main factor of rumble strips application decision. The subsequent factor selected by 90 percent of the State DOTs was the asphalt layer thickness and condition.

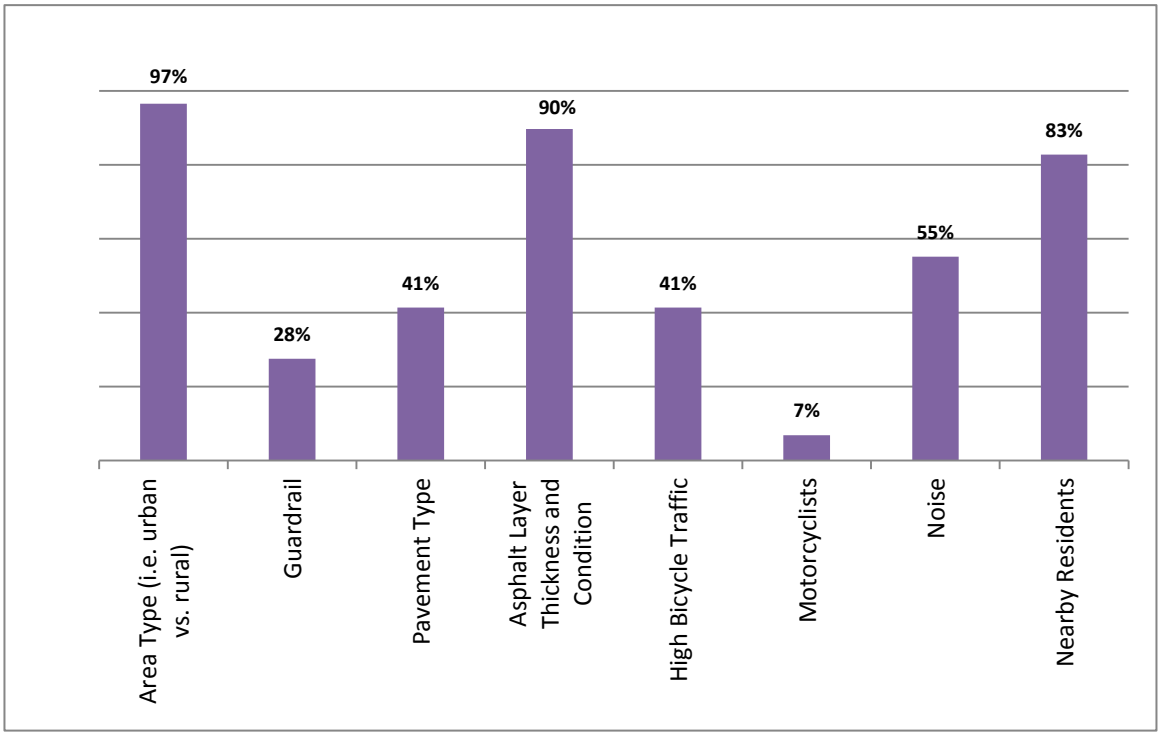

Figure 18: Conditions may Prevent Rumble Strips/Stripes Installations (DOT Survey: Q5).

Concerning rumble strips maintenance, different processes are used. According to the survey, rumble strips are sealed by 19 percent of the states, 15 percent do it every 3 years, and 4 percent do it every year. Eighty percent of the states responded they treat rumble strips at the same time with pavement; reinstalled through resurfacing when needed. Some states do not have any maintenance procedure for rumble strips. Those differences between states might be explained by the different regulations.

As shown in figure 19, 14 percent of the DOTs follow the NCHRP Report 641 guidelines directly and 50 percent follow with some modification. However, 33 percent responded they are using their own guidelines, while 1 state responded they do not have any policy for rumble strips.

Those differences in regulations appeared in rumble strips' implementation and usage, as well as in the maintenance, throughout the entire survey.

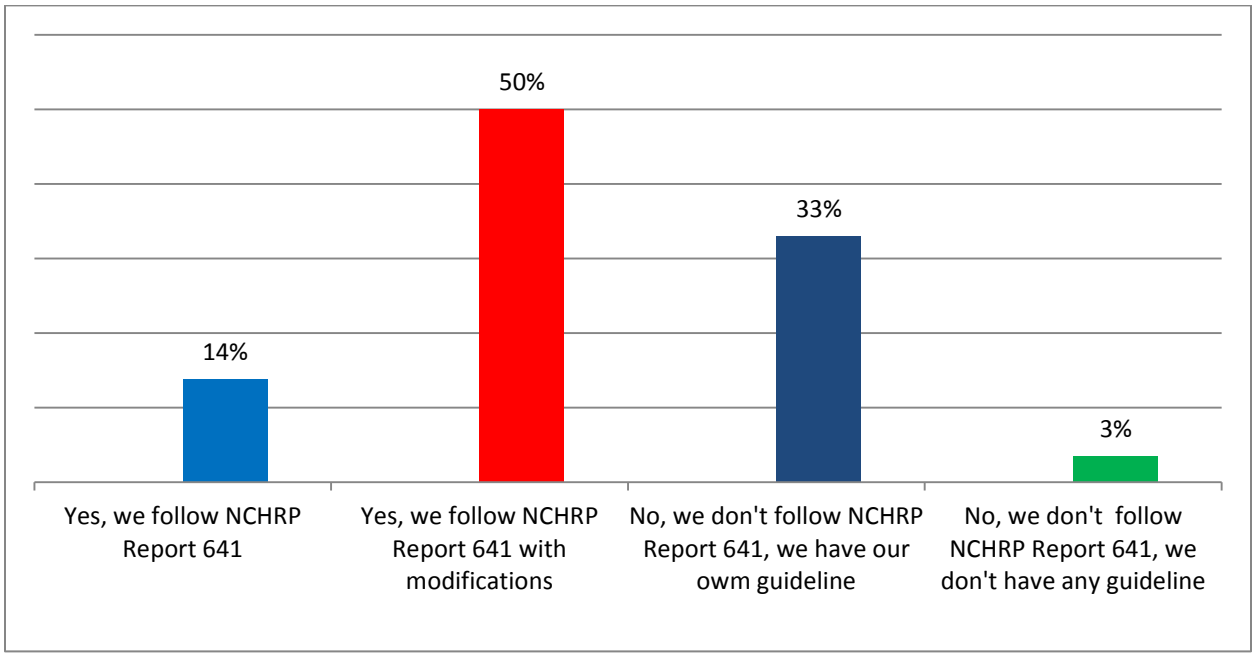

Figure 19: Compliance to NCHRP Report 641 (DOT Survey: Q3).

Table 5: Transportation Agency Responses Concerning the Application of Shoulder Rumble Strips on Different Roadway Types

Freeway		Two-lane Highway		Multilane Highway			
				Rural		Urban	
Rural	Urban	Rural	Urban	Divided	Undivided	Divided	Undivided
Alabama	Alabama	Alabama*		Alabama	Alabama*	Alabama	
Alaska*		Alaska					
Arizona*		Arizona*		Arizona	Arizona*	Arizona	
Arkansas	Arkansas	Arkansas*	Arkansas*		Arkansas*		
Connecticut	Connecticut						
	Florida	Florida*			Florida*		
Idaho		Idaho*		Idaho	Idaho		
Indiana	Indiana	Indiana*			Indiana		
Kentucky	Kentucky	Kentucky*	Kentucky*	Kentucky	Kentucky*	Kentucky	Kentucky
Maine	Maine	Maine					
Massachusetts	Massachusetts	Massachusetts		Massachusetts	Massachusetts	Massachusetts	Massachusetts
Michigan	Michigan	Michigan			Michigan		
Mississippi*	Mississippi*	Mississippi*	Mississippi*	Mississippi	Mississippi*	Mississippi	
Montana		Montana			Montana		
		Nevada*		Nevada	Nevada		
New Hampshire	New Hampshire	New Hampshire	New Hampshire		New Hampshire		
New Jersey	New Jersey						
New Mexico*		New Mexico*			New Mexico*		
North Dakota	North Dakota	North Dakota*		North Dakota	North Dakota*	North Dakota	
Ohio		Ohio*			Ohio		
Oklahoma	Oklahoma	Oklahoma			Oklahoma		
Oregon		Oregon*		Oregon	Oregon	Oregon	
Pennsylvania	Pennsylvania	Pennsylvania	Pennsylvania	Pennsylvania	Pennsylvania	Pennsylvania	Pennsylvania
South Carolina	South Carolina*	South Carolina			South Carolina*		

Freeway		Two-lane Highway		Multilane Highway			
Rural	**Urban**	**Rural**	**Urban**	**Rural**		**Urban**	
				Divided	**Undivided**	**Divided**	**Undivided**
South Dakota*		South Dakota*			South Dakota*		
Tennessee*	Tennessee*	Tennessee*	Tennessee*		Tennessee*		
Texas*	Texas*	Texas*	Texas*	Texas	Texas*		
Wisconsin	Wisconsin	Wisconsin			Wisconsin		
Wyoming	Wyoming	Wyoming			Wyoming		

* Rumble Stripes Used Based on Requirement

Table 6: Transportation Agency Responses Concerning the Application of Centerline Rumble Strips on Different Roadway Types

Rural Multilane Undivided Highways	**Rural Two-lane Highways**
	Alabama
	Alaska
Arizona	Arizona
Arkansas	Arkansas
	Connecticut
	Florida
Idaho	Idaho
	Indiana
	Kentucky
	Maine
	Michigan
	Mississippi
Montana	Montana
Nevada	Nevada
	New Hampshire
	New Jersey
	New Mexico
	North Dakota
	Ohio
Oregon	Oregon
	Pennsylvania
Pennsylvania	
South Carolina	
South Dakota	South Dakota
Texas	Texas

Transportation Agency Responses Concerning the Impact on Bicyclists, Motorcyclists, and Nearby Residents

This section summarizes the practices of State DOTs to accommodate non-conventional road users, i.e., bicyclists, motorcyclists, and nearby residents.

Figures 20 and 21 illustrate that 86 percent of the State DOTs have received complaints from bicyclists about shoulder rumble strips, and 86 percent of the respondents have made provisions to accommodate bicyclists by either not installing SRS on routes with high bicycle traffic or using alternative rumble strips design.

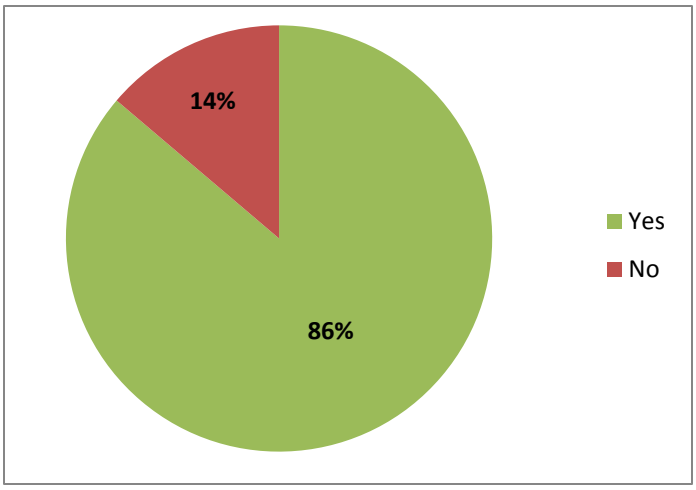

Figure 20: Complaints about Shoulder Rumble Strips/Strips from Bicyclists (DOT Survey: Q11).

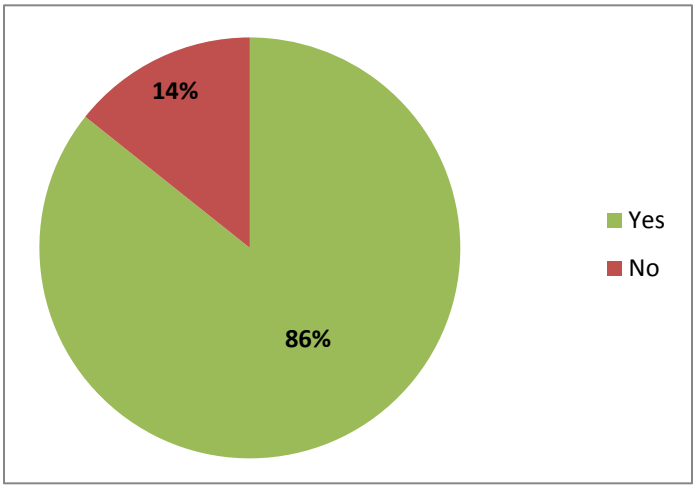

Figure 21: Provisions to Accommodate Bicyclists in DOTs (DOT Survey: Q12).

Several studies have concluded that rumble strips do not pose measurable risk to motorcyclists. The results from the survey showed that only 12 percent of the DOTs are using alternative centerline rumble strips design as shown in figure 22 to accommodate motorcyclists. The remaining 88 percent uses conventional CLRS designs.

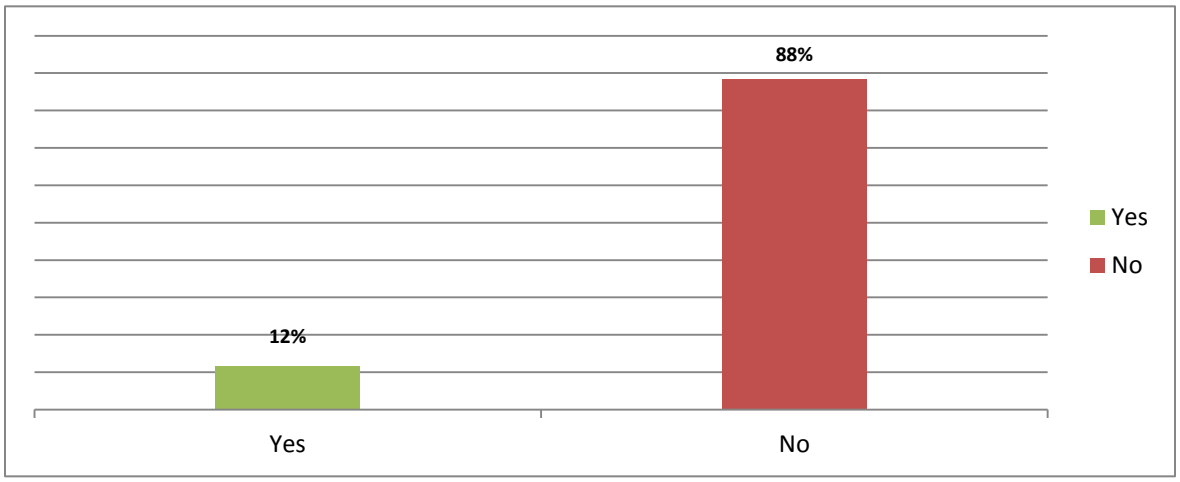

Figure 22: Considerations for Motorcyclists when Placing Centerline Rumble Strips (DOT Survey: Q14).

It was concluded in a previous survey conducted in Utah [60] that advanced warning about shoulder rumble strips is not required as they are visible enough by themselves. Among the survey respondents, three states use warning signs to alert bicyclists and motorcyclists of the presence of rumble strips. The survey results showed that 92 percent of the State DOTs never received any crash reports about bicyclists or motorcyclists due to rumble strips, as shown in figure 23. With respect to concerns reported by some transportation agencies about the visibility and retroreflectivity of pavement markings installed on rumble strips (i.e., rumble stripes), 16 percent of the State DOTs respondents take special measure to increase the nighttime visibility of rumble stripes. Twenty-four of the 29 respondents reported that there was not any reduction in nighttime visibility of pavement markings installed on rumble strips.

Regarding residents living nearby rumble strips, 86 percent of the State DOTs respondents have received complaints about the noise produced by rumble strips. Consequently, 55 percent of State agencies considered using alternative rumble strips designs to reduce noise as shown in figure 24.

As indicated from the State DOTs survey in figure 18, accommodating all road users, such as providing a “Bicycle Friendly Rumble Strips”, is considered by 41 percent DOTs. In general, DOTs guidelines do not recommend installing shoulder rumble strips on routes designated as a bicycle routes or high bicycle-use areas. Some DOTs polices have mitigated the adverse effect of rumble strips on bicyclists through various remedial measures. Providing 4 feet shoulders, or 5 feet with guardrail as the bare minimum to ensure sufficient space for bicyclists.

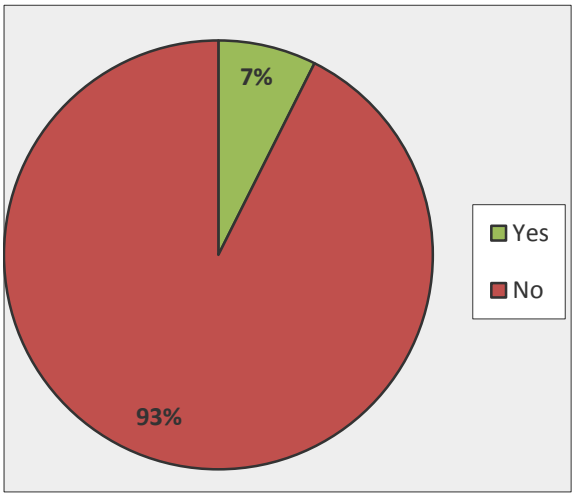

Figure 23: Report of Motorcyclists/Bicyclists Crash due to Rumble Strips (DOT Survey: Q19).

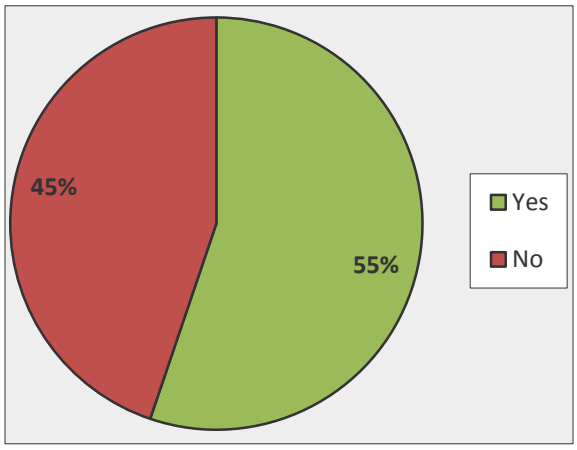

Figure 24: Considerations of Alternative Rumble Strips to Reduce Noise by DOTs (DOT Survey: Q18).

States such as Alaska and Colorado require a minimum 6 feet shoulder. Florida requires at least 4 feet of continuous clear riding surface where bicyclists are expected. Adjusting rumble strips

placement and dimensions such as placing shoulder rumble strips as close to the edge line, and using narrower and shallower designs are other remedial measures used by several states. Providing periodic gaps of at least 12 feet every 40 or 60 feet is commonly utilized to enhance cyclists' maneuverability to avoid debris along the shoulder, in making turns, or for passing other cyclists. If combined shoulder and centerline rumble strips is to be used on narrow roads with bicycle traffic, a modified lateral width rumble strips is considered to mitigate the adverse effect on vehicle/bicycle interaction. Many states consider nearby residents when installing rumble strips in residential areas by either not installing rumble strips within urban limits or, if warranted, by examining crash experience, and using modified shallower depth rumble strips.

BICYCLISTS SURVEY IN WYOMING

This section discusses the results from the survey questionnaire collected from the bicyclist's community in Wyoming. Several biking communities and clubs were identified in the State of Wyoming and their members' email contact information was acquired. Respondents were limited to adults over 18 years of age with enough biking experience in Wyoming. Online surveys have become more common recently because of their advantages over ordinary survey approaches i.e., handouts and interactive surveys. Out of the 172 sent email invitations, 57 bicyclists responded to the online survey questionnaire.

Out of the 57 respondents, 53 percent were males, 43 percent were between 26 and 50, 46 percent were between 51 and 65 years old, and the remainder were either over 65 or between 18 and 25. Figures 25 and 26 illustrate the respondents' biking experience and seriousness. Fifty-seven percent responded they use their bikes every day, as shown in figure 26.

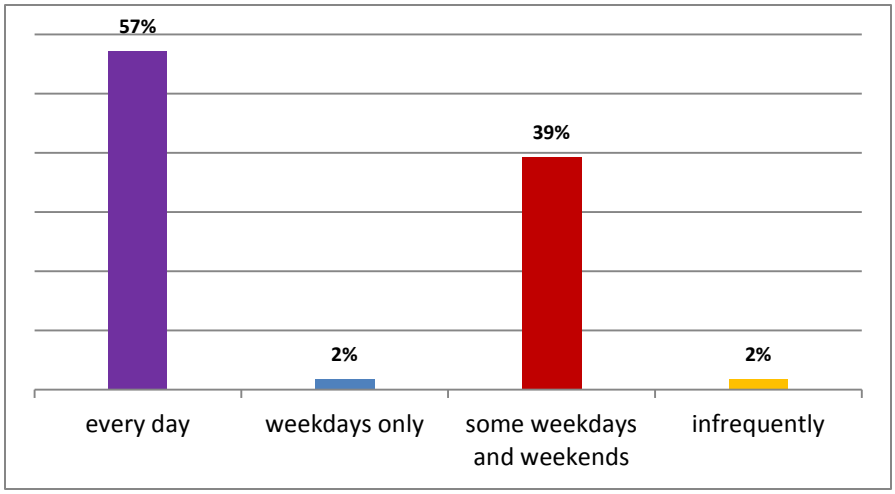

Figure 25: How Frequently Do Bicyclists Ride their Bikes (Bicyclists Survey: Q5)?

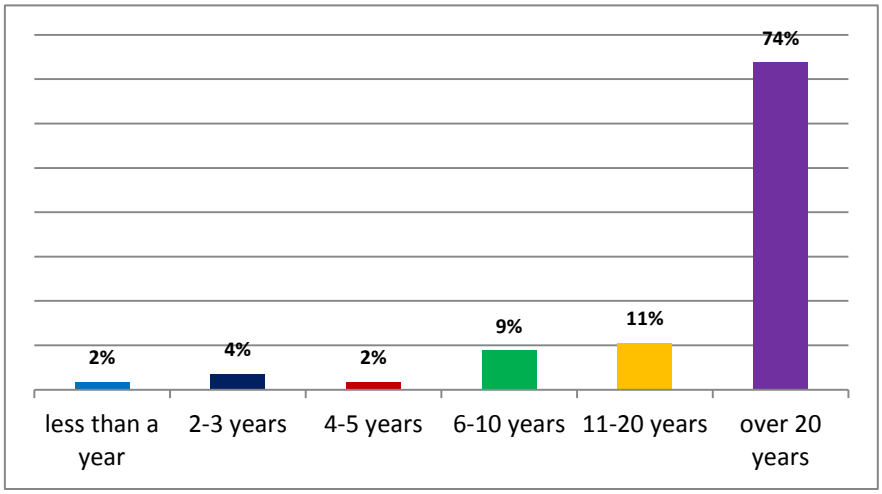

Figure 26: Bicycling Experience (Bicyclists Survey: Q3).

The majority of bicyclists ride their bikes on city streets, country and county roads, and state highways as illustrated in figure 27. The most common bike types reported in the survey were road and mountain bikes. Eighty-nine percent bicyclists responded that they ride on city streets. Additionally, 81 percent and 75 percent responded they ride on country roads and state highways respectively. Moreover, 67 percent ride their bike on bike trails/paths as well.

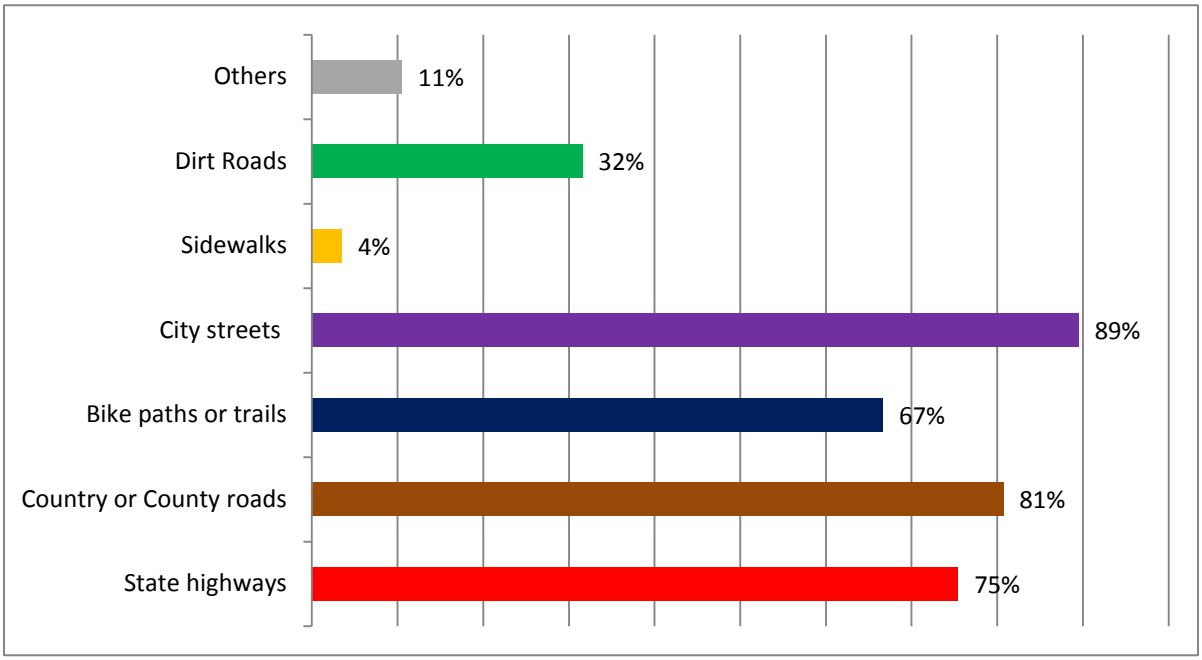

Figure 27: Where do Bicyclists Ride Mostly (Bicyclists Survey: Q7)?

Bicyclists' Experience and Opinion on Shoulder Rumble Strips/Stripes

About ninety-five percent of bicyclists responded that they encountered rumble strips while riding their bikes in Wyoming. Although most bicyclists reported that traversing rumble strips for the first time was a "bad" experience, 61 percent indicated that they are comfortable riding on roadways with rumble strips. Also, 57 percent indicated that providing an advanced warning is not necessary and about 58 percent do not consider rumble strips when choosing their routes.

The results are coherent and suggest that bicyclists are getting used to shoulder rumble strips and tolerate their presence. The fact that even if rumble strips are surprising to some bicyclists and might render the controllability of their bikes, 96 percent of bicyclists stated that they never had any crashes due to them.

Ninety six percent of bicyclists believe as drivers that rumble strips are useful and improve their safety on roads, and 94 percent are ready to accept more shoulder rumble strips implementation in the State of Wyoming. However, respondents stated that providing enough clear shoulder width, and use narrower rumble strips design are more important.

As shown in the figure 28, one third of the respondents indicated that 4 feet clear shoulder width might be enough for them to ride comfortably on roads with shoulder rumble strips. Bicyclists were asked to rank five given options to increase their riding comfort on roads with shoulder rumble strips, where 1 is the most favorable option and 5 is the least one.

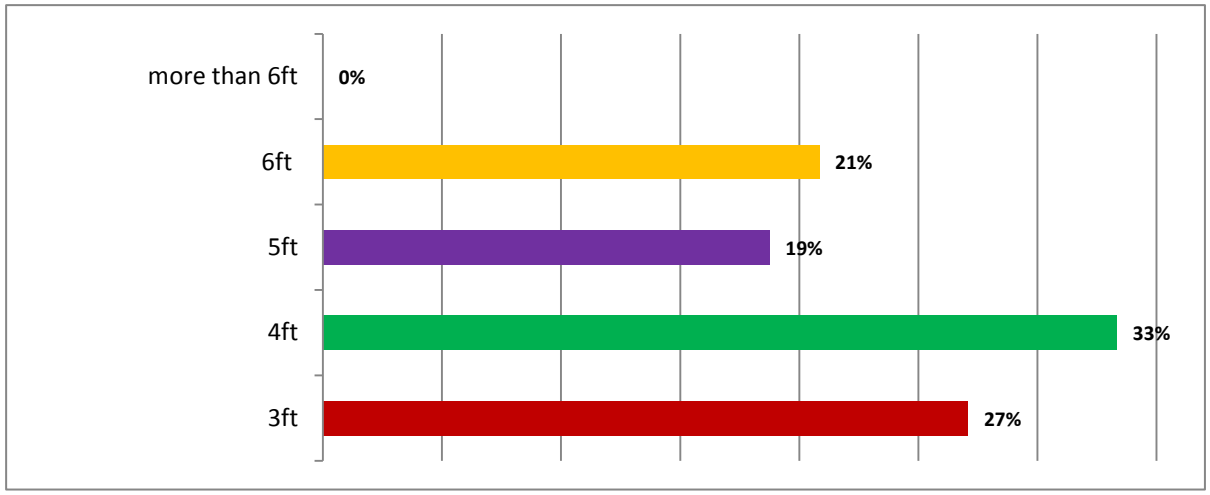

Figure 28: Minimum Clear Shoulder Width Recommendations from Bicyclists (Bicyclists Survey: Q13).

According to figure 29, the most favorable option selected by 47 percent was to increase the clear shoulder width, followed by placing SRS close to traffic lane, and sweeping the shoulder more frequently. It is worth mentioning that the second and third option choices will result in a wider clear shoulder available to bicyclists. However, bicyclists' choice "Do not install SRS on roads with significant bicycle traffic" as their least favorable option explicitly indicates that they would accept more SRS implementation in the State of Wyoming.

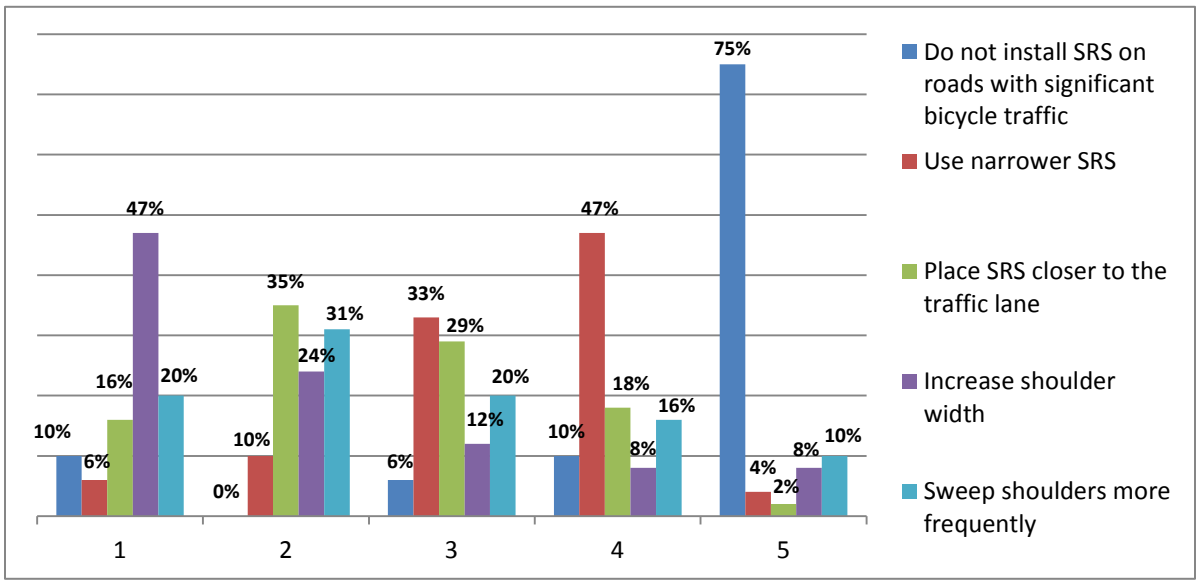

Figure 29: Recommendations on Accommodating Bicyclists (Bicyclists Survey: Q16).

As shown in figure 30, 54 percent of the respondents are in agreement with the existing practice of WYDOT of providing 12 feet gap every 60 feet, while 30 percent requested longer but less frequent gaps. Many bicylists indicated the gaps that are positioned more carefully than frequently would help in increasing their riding comfort.

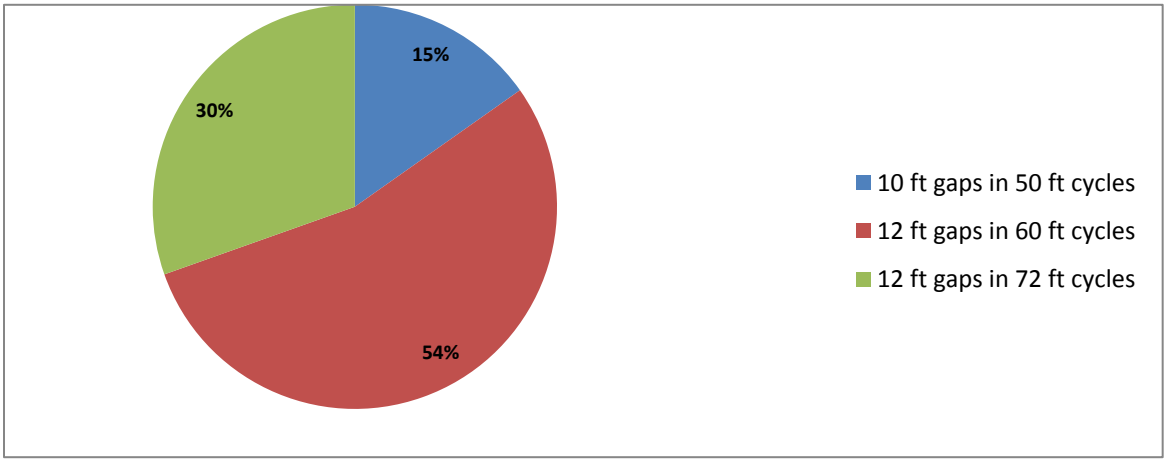

Figure 30 : Recommended Bicyclists Gaps (Bicyclists Survey: Q14).

NEARBY RESIDENTS SURVEY

Another survey was conducted to investigate the effect of the noise associated with rumble strips on nearby residents in the State of Wyoming. A set of questions asking about rumble strips were

presented to residents living within one mile from rumble strips. The survey was disseminated through three survey approaches: mail, online questionnaire, and door to door interactive interviews. A total of 50 responses were collected out of 425 survey invitations sent. It is worth mentioning that about 125 of the targeted door to door interactive survey subjects chose not to complete the survey because they felt that the noise generated by rumble strips is not an issue.

Several locations were identified where rumble strips are used in residential areas. WYDOT provided highway names and mile posts where rumble strips are installed in or nearby residential areas. Google Earth was used to retrieve mailing addresses for residents. Cheyenne, Gillette, and Sheridan were among the cities where survey questionnaire were sent by mail. Using a school email list, online questionnaires were sent to the parents of elementary school children living along WY 210. A door to door survey was conducted in Cheyenne for two days. Cheyenne was selected for this approach as there are residents living within 100 feet of a busy interstate I-80. Surveys were conducted during the weekends to have access to more people.

Distribution of age and educational level for the survey respondents from different locations in Wyoming are given in figures 31 and 32.

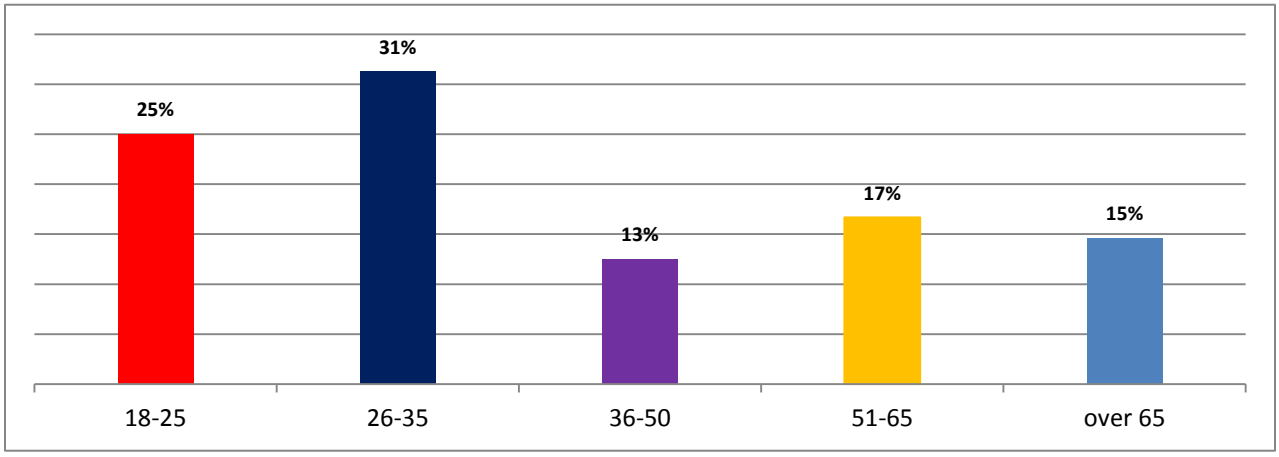

Figure 31: Age of the Respondents (Residents Survey: Q17).

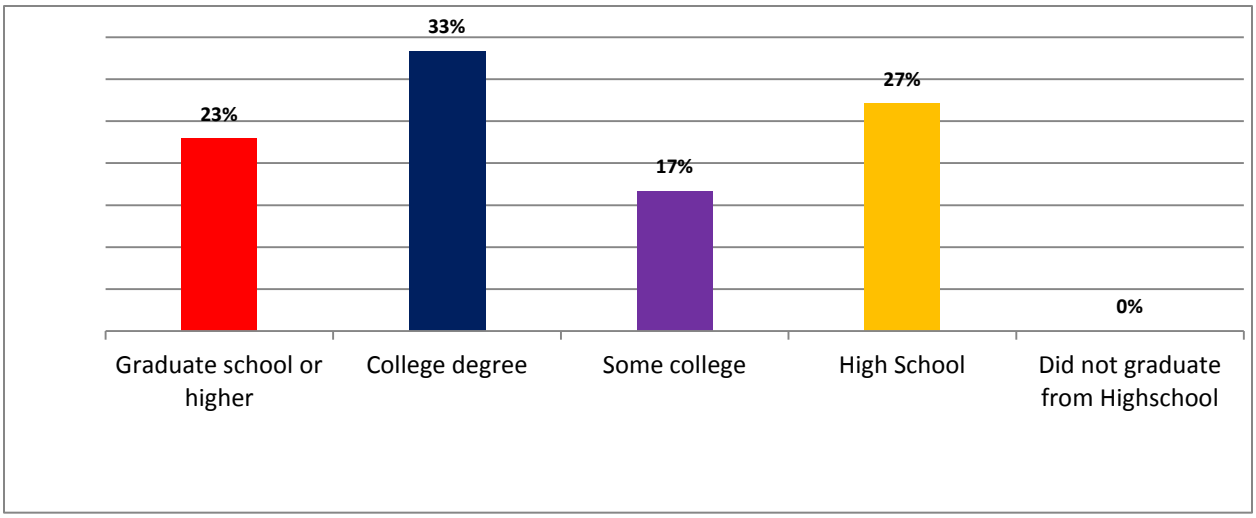

Figure 32: Education Level of the Respondents (Residents Survey: Q18).

Nearby Residents Experience with Shoulder Rumble Strips

Intermittent rumble strips design is used in Wyoming to accommodate nearby residents. Out of the 50 respondents, 44 percent live within 100 feet, 44 percent between 100 to 300 feet, and the remaining 12 percent were from 300 feet to 1 mile.

Although the rumble strips used nearby residents have intermittent design, nearby residents reported that they can hear the noise from their houses. The majority stated that they hear it more than 10 times a day and mostly during evening, late night, and midnight as shown in figures 33 and 34. It should be noted that reporting the noise more frequently during evening and night times might be associated with less noise levels inside home and residents are expected consistently to be home. Also, nighttime is when drivers are expected to veer over rumble strips more often.

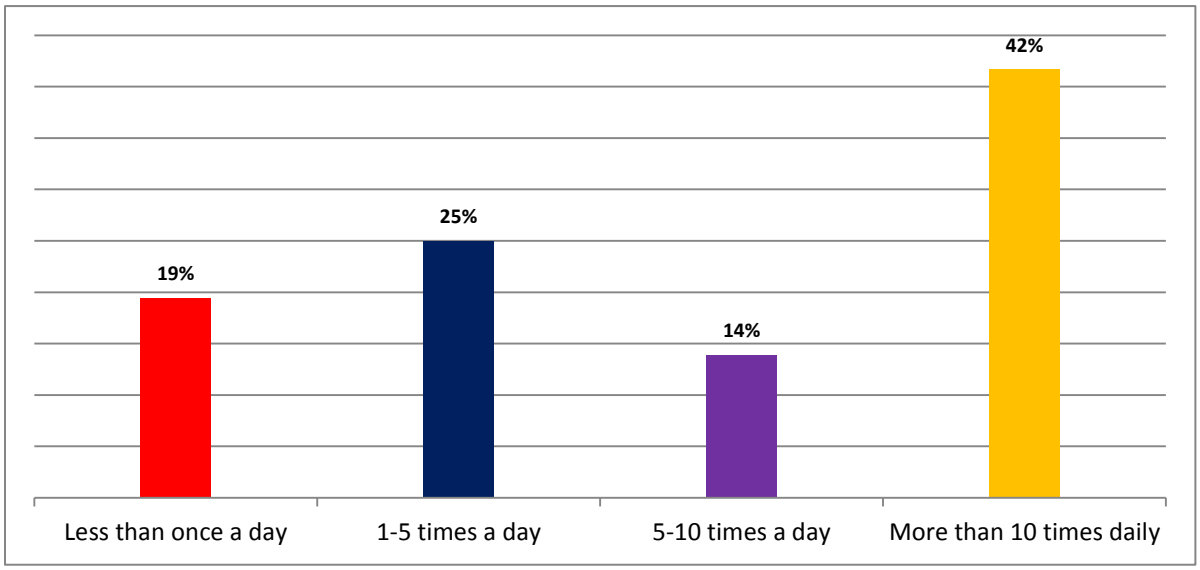

Figure 33: Frequency of Noise (Residents Survey: Q5).

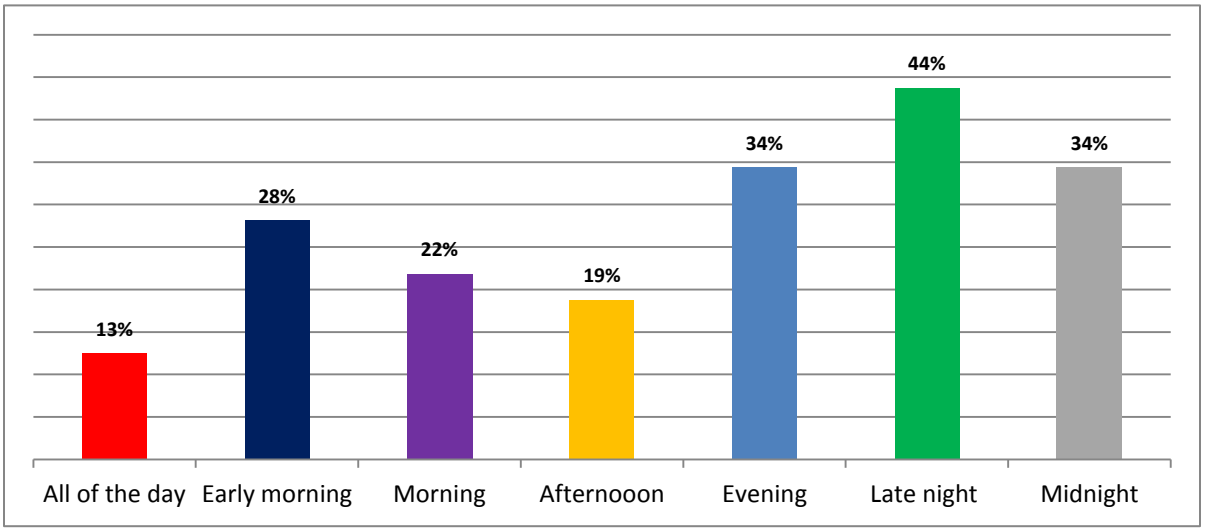

Figure 34: What Time of the Day Noise can be Heard (Residents Survey: Q6)?

Although that about 69 percent of residents indicated that they hear rumble strips noise from their homes, according to figure 35, 84 percent of the residents believed that the noise is acceptable, and about 81 percent thought that the level of noise is low to moderate as shown in figure 36.

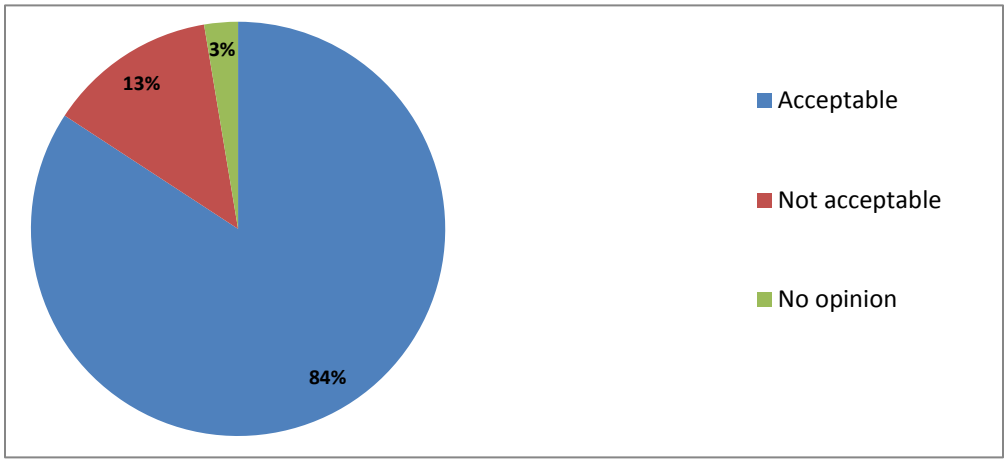

Figure 35: Acceptability of Noise to the Residents (Residents Survey: Q8).

Thirty percent of the respondents stated that using quieter design might alleviate the noise issue, 34 percent indicated that rumble strips in their current form are important to save driver's lives, and 32 percent had no preference as presented in figure 37.

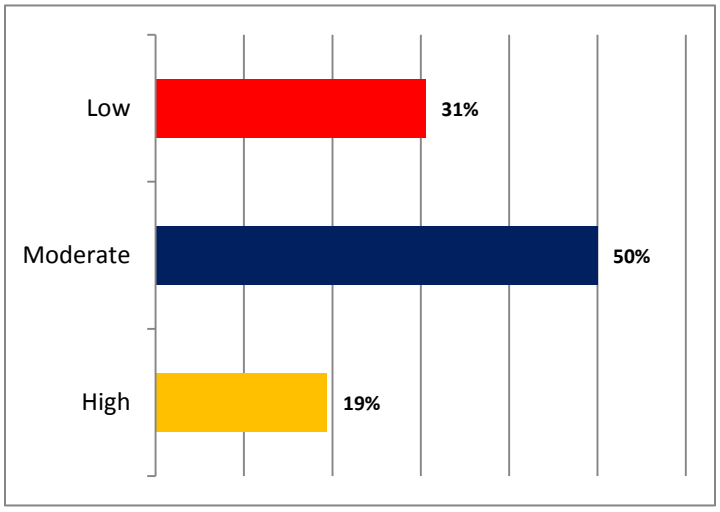

Figure 36: Level of Noise can be Heard from the Residence (Residents Survey: Q7).

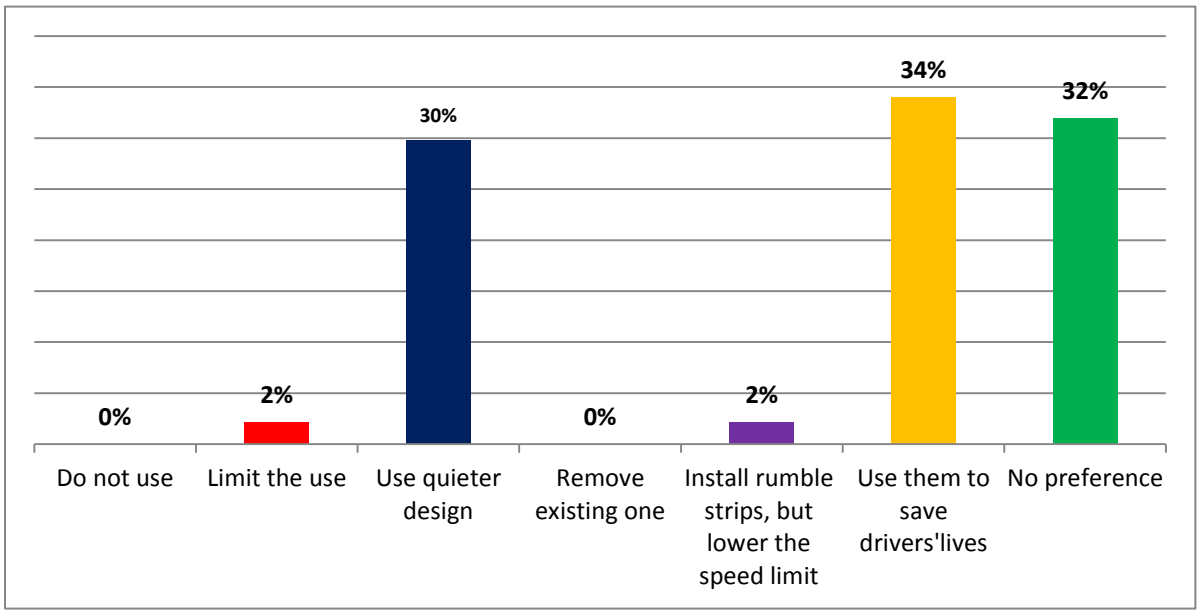

Figure 37 : Preferences of the Residents (Residents Survey: Q9).

Driving Experience with Shoulder Rumble Strips

Nearby residents were surveyed as drivers in one section of the questionnaire. The distribution of the respondents driving experience is shown in figure 38, only 4 percent are not drivers.

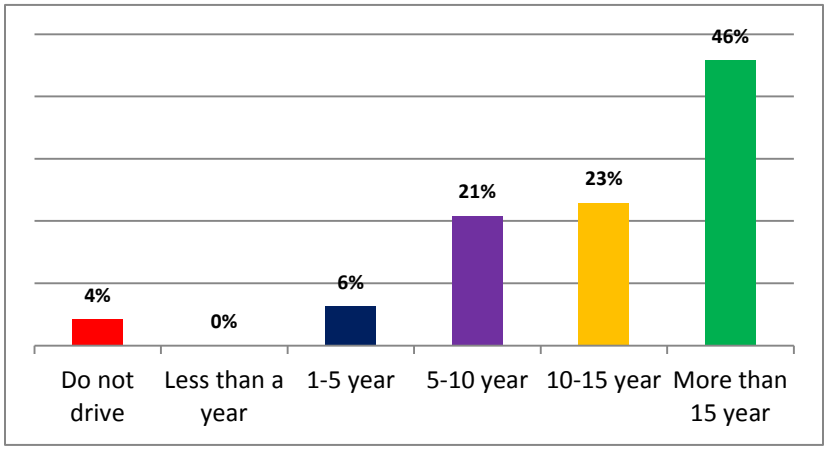

Figure 38: Driving Experiences of Respondents (Residents Survey: Q11).

Figure 39 indicates that almost all drivers have encountered rumble strips while driving, and 94 percent believe that rumble strips enhance public safety as shown in figure 40**.**

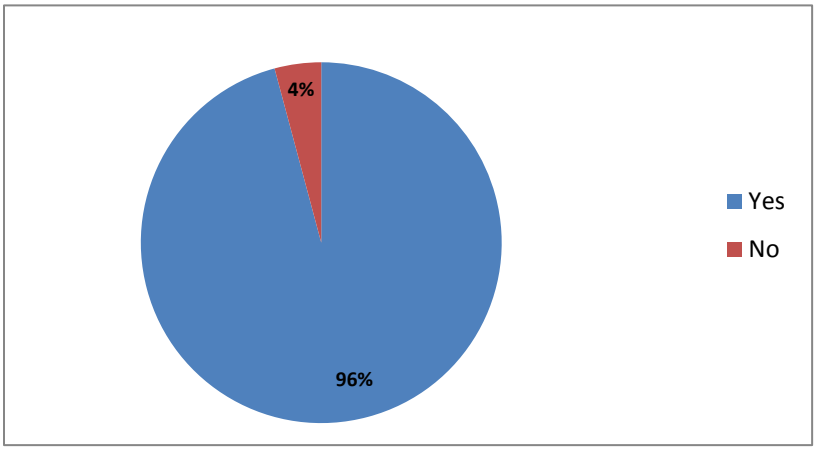

Figure 39: Experience with Shoulder Rumble Strips (Residents Survey: Q12).

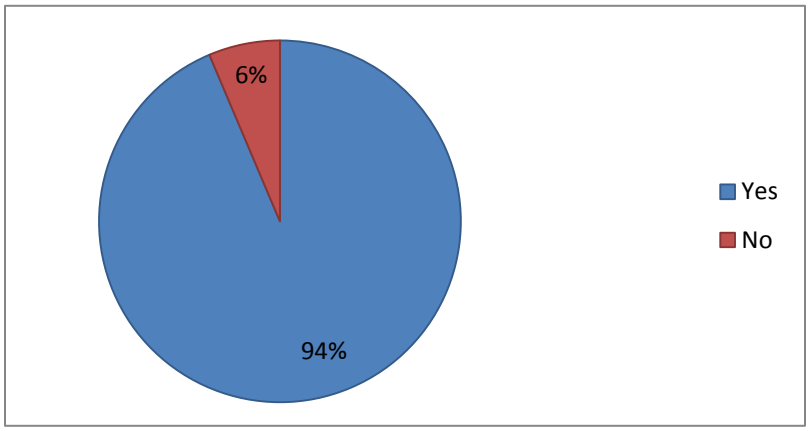

Figure 40: Do Rumble Strips Enhance Public Driving Safety (Residents Survey: Q14)?

The survey was disseminated by mail, online, and by conducting door to door interviews targeting residents living near rumble strips. Among the 50 respondents, 88.5 percent are living within 500 feet from rumble strips. About 27 percent of the interviewed residents indicated that the noise from rumble strips is not an issue and did not care about completing the survey. Although intermittent residential rumble strips design is utilized in urban areas in Wyoming, two-thirds of nearby residents can still hear the noise caused by rumble strips. Half of the residents categorized the level of noise as moderate, 42 percent responded that they can hear it more than 10 times a day. The time period at which they hear it is mostly evening, night and early morning. The survey results indicated that residents who live within 300 feet at the first line of houses might notice the noise, but the first line of houses serves as a noise barrier for

houses farther away and hence noise level is negligible for houses behind the first line. Despite this fact, 84 percent of the nearby residents find the noise level acceptable and 98 percent of them are ready to tolerate it indicating that rumble strips save lives. In fact, most of the residents have experienced rumble strips as drivers and attest of its effectiveness in enhancing drivers' safety. About 23 percent responded they were 'surprised' when they came in contact with rumble strips for the first time and 29 percent responded that they were alerted by rumble strips when they veered from their traffic lanes. Moreover, 96 percent of them think that the vibrations and noise created by rumble strips are enough to alert the driver. To conclude, residents would mostly like to have, if possible, a quieter design, and the idea of a sound barrier has been mentioned multiple times in residents' general comments.

WYOMING DOT SURVEY

In order to collect feedback for WYDOT engineers, a fourth survey was designed and disseminated online to WYDOT. A total of 45 engineers at WYDOT completed the survey.

Parameters of Installation of Rumble Strips/Stripes

Various factors govern the design and application of rumble strips/stripes; the area type, traffic volume, speed limit, lane width, shoulder width, clear path, crash history, pavement type, pavement depth, bicycle volume, among other factors. According to table 7, the factors selected by WYDOT to govern rumble strips applications were; crash history, shoulder width, area type, and posted speed limit.

One of the main factors affecting the installation of rumble strips/stripes is the shoulder width. The survey asked questions about the recommended shoulder width to install shoulder and centerline rumble strips/stripes. The results indicated that 4 feet is recommended for all roadway types except urban two-lane highways. Above 44 percent of WYDOT engineers stated that shoulder and centerline rumble strips and stripes should not be installed on urban two-lane highways as shown in figures 41 and 42. It was also concluded that rumble stripes are not recommended where rumble strips can be installed.

Table 7: Rank of Features Affecting Rumble Strips Installation

Ranks	Features Directly Affect Installation of Rumble Strips
1	Lane Departure Crash History
2	Shoulder Width
3	Area Type (i.e. urban vs. rural)
4	Speed
5	Bicyclists, Traffic Volume
6	Roadway Classification
7	Lateral Clearance
8	Guardrail
9	Pavement Condition
10	Asphalt Layer Thickness
11	Pavement Type
12	Motorcyclists
13	Noise

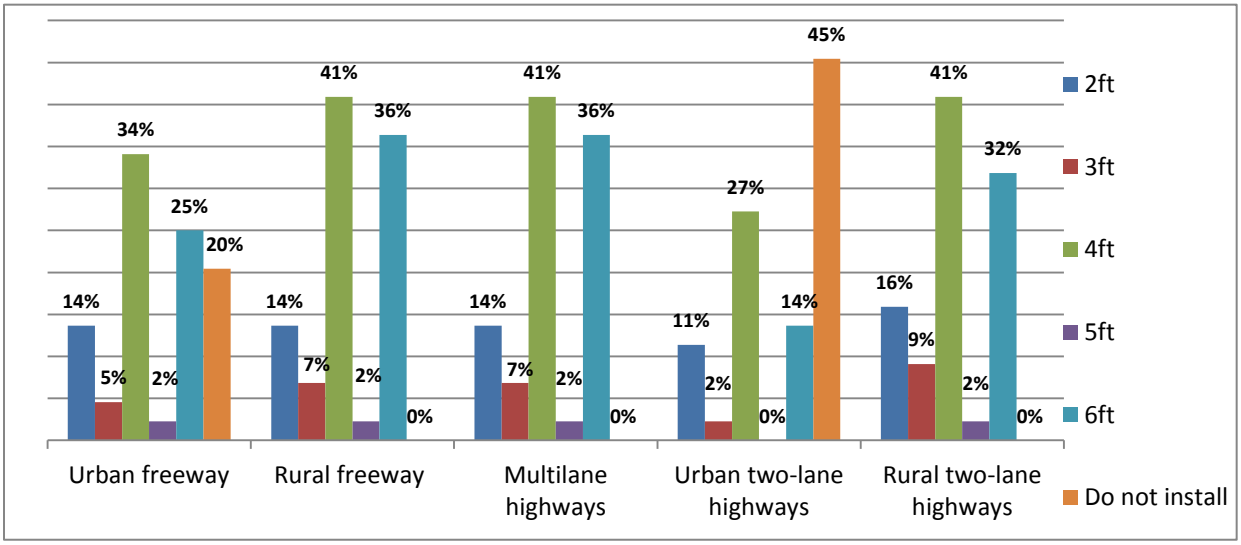

Figure 41: Minimum Shoulder Width Recommendations for Combined Use of SRS and CLRS (WYDOT Survey: Q15).

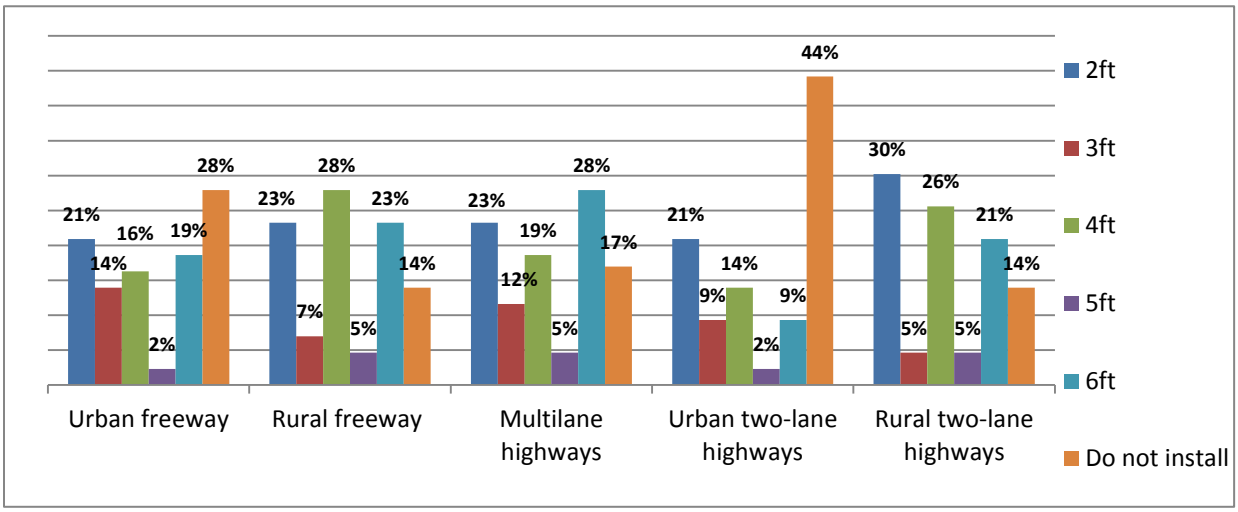

Figure 42: Minimum Shoulder Width Recommendations for Rumble Stripes (WYDOT Survey: Q4).

Lane width was another important governing factor in rumble strips application; 12 feet lane width was recommended as a minimum requirement on most roadway types by many WYDOT engineers. Consistently with previous recommendations; rumble strips are not recommended by 37 percent on urban two-lane highways, and 27 percent on multilane highways (figure 43). Similar results were reported for the centerline rumble strips. Thirty-six of WYDOT engineers indicated that 12 feet lane width is required to install centerline rumble strips on rural freeway, 37 percent for multilane highways, and 49 percent for rural two-lane highways. However, 39 percent indicated that centerline rumble strips should not be installed on urban two-lane highways (figure 44).

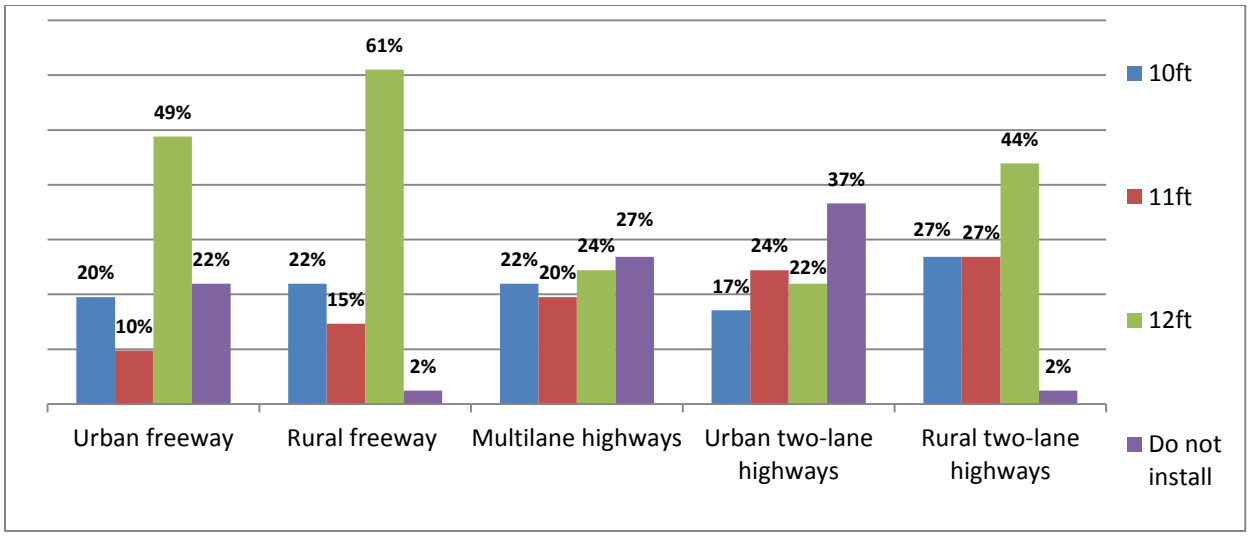

Figure 43: Minimum Lane Width to Install SRS (WYDOT Survey: Q10).

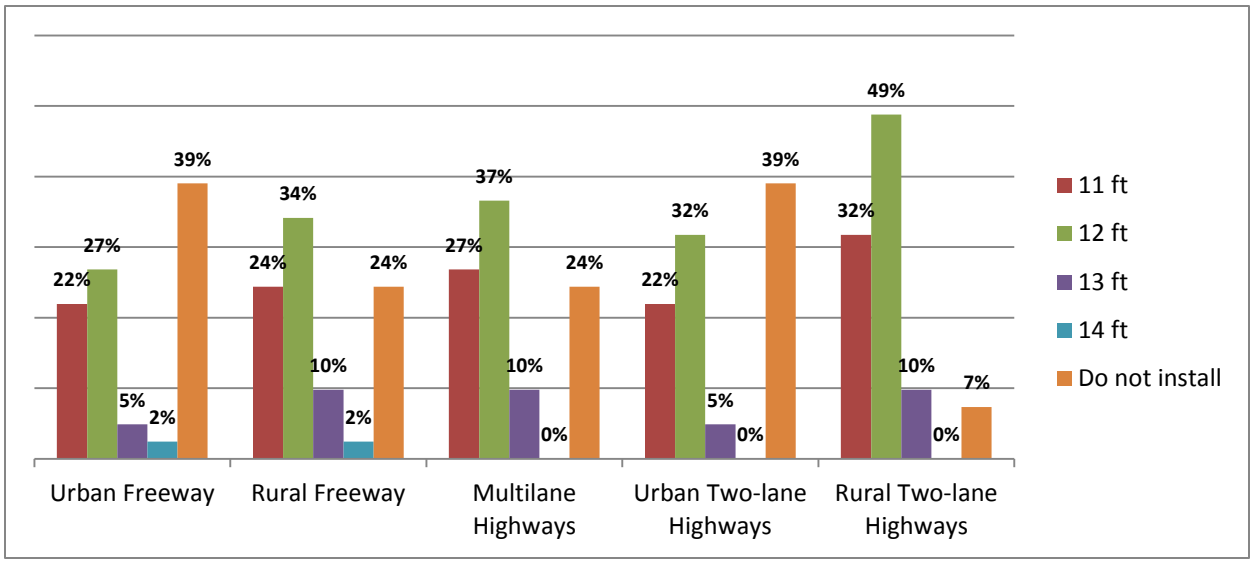

Figure 44: Minimum Lane Width to Install CLRS (WYDOT Survey: Q14).

Comparable results were reported for the combination of centerline and shoulder rumble strips, the results for the lane width are identical to the centerline rumble strips, 49 percent of WYDOT engineers indicated that 12 feet lane width should be required to install SRS and CLRS in combination on rural two-lane highways.

Posted speed limit is another factor of importance to WYDOT engineers; about 43 percent of the respondents indicated that the minimum speed limit should be 55 mi/h, while 38 percent stated

that 45 mi/h should be the minimum speed limit to justify installing rumble strips on roadways (figure 45). The majority of the respondents stated that the recommended pavement thickness should be 4 inches or more and in 'good' to 'excellent' condition (figure 46).

Concerning the asphalt layer, multiple parameters can influence the installation of rumble strips/stripes. Primarily, the minimum thickness of asphalt layer, and then the recommended condition of the layer.

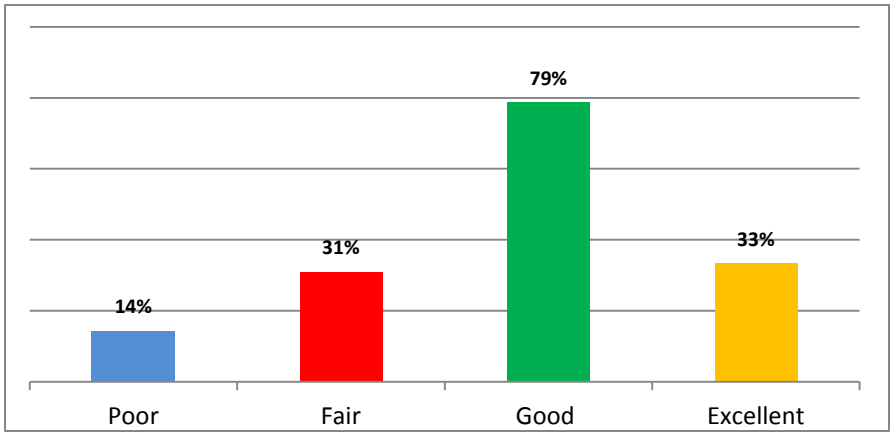

Figure 45: Recommended Condition of Asphalt Layer to Install Rumble Strips (WYDOT Survey: Q8).

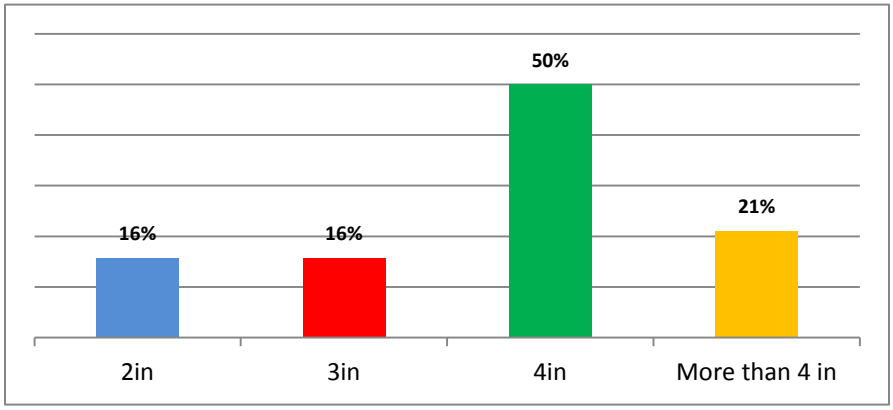

Figure 46: Minimum Thickness of the Asphalt Layer to Install Rumble Strips (WYDOT Survey: Q7).

In other states, a minimum Average Daily Traffic (ADT) is a requirement to install rumble strips/stripes. However, in Wyoming, 58 percent of WYDOT engineers stated that there should not be any requirement regarding ADT. Figure 47 illustrates WYDOT engineers' recommendation on areas where rumble strips should be discontinued to avoid consequences.

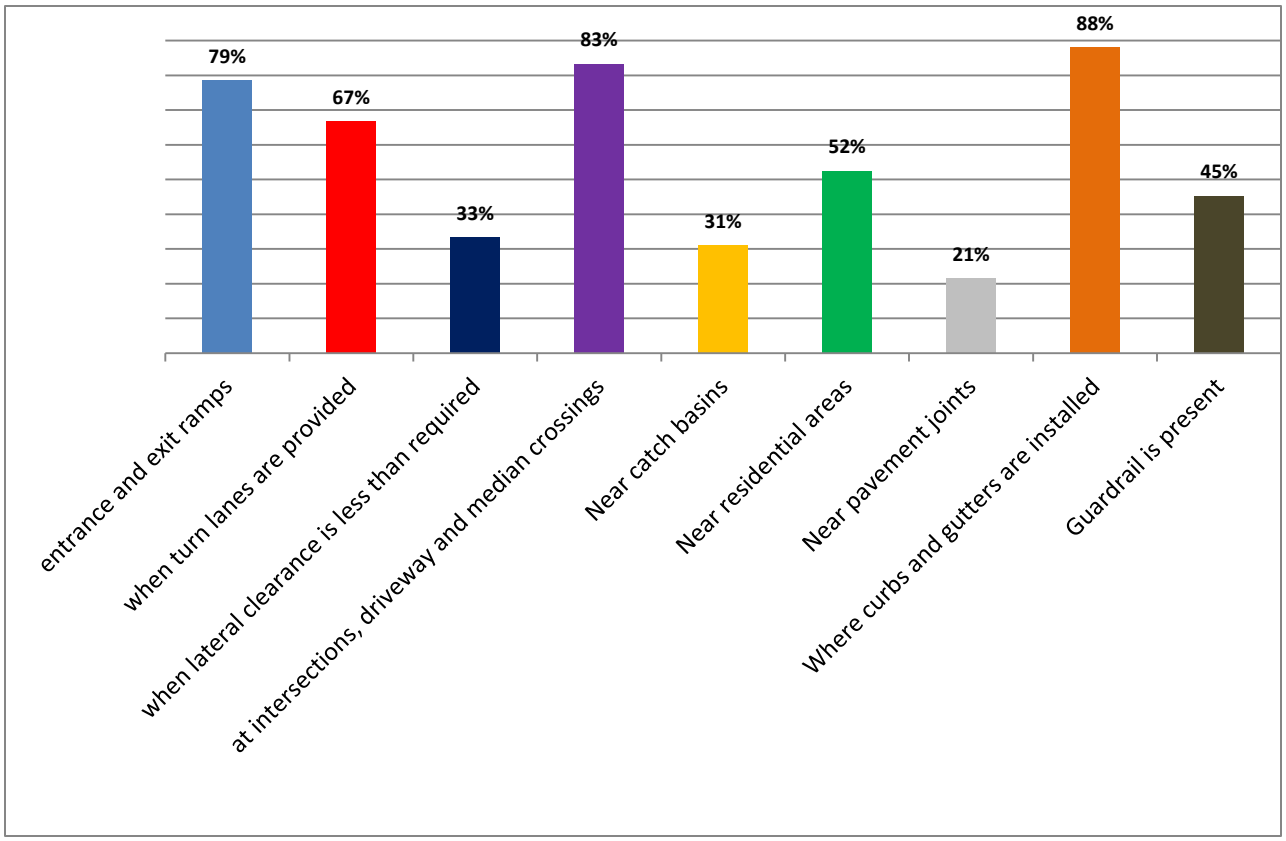

Figure 47: Where SRS should be Discontinued (WYDOT Survey: Q12)?

Rumble Strips Implantation and Accommodation to All Roadway Users

The survey results showed a recommendation of installing centerline rumble strips on all rural two-lane and rural multilane undivided highways. Only 40 percent supported the application of rumble strips on suburban two-lane and multilane undivided highways. This percentage increased to more than 50 percent for locations with high number of head-on and opposite sideswipe crashes. Centerline rumble strips were recommended to be discontinued at bridges, intersections, driveways, residential areas, and passing zones.

Although the wide body of the literature concluded that centerline rumble strips do not pose adverse effects on motorcyclists, the survey results indicated that by decreasing the depth below 0.5 inch, and not installing centerline rumble strips in passing zones can better accommodate motorcyclists as shown in figure 48.

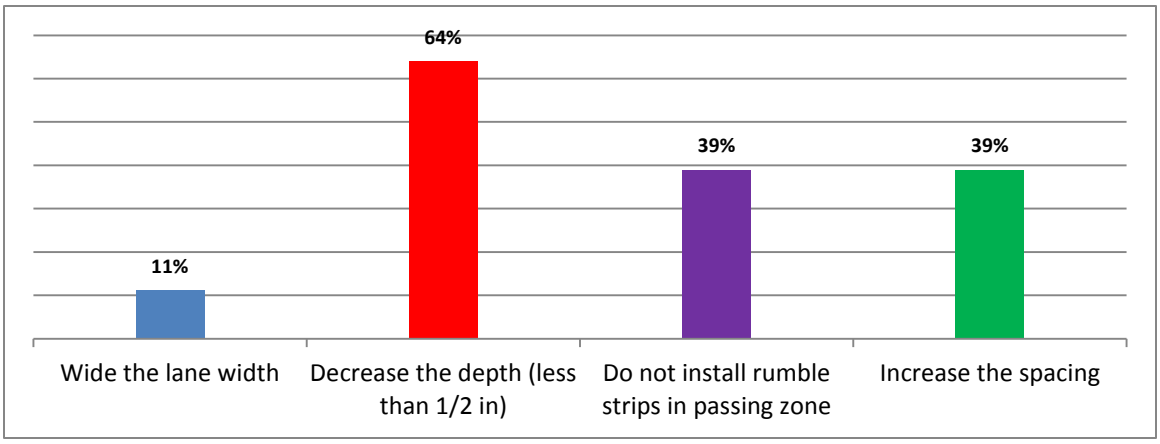

Figure 48: Accommodation of Motorcyclists on Roadways with CLRS (WYDOT Survey: Q17).

FHWA requires that the design and installation of rumble strips should accommodate all road users. Cyclists are uniquely identified as being negatively affected most by rumble strips because in situations where rumble strips are constructed on the shoulder without leaving room for cyclists, the cyclists are forced to ride on the travel lanes where they are exposed to dangers from vehicular traffic. In this survey, multiple questions were asked on how to accommodate bicyclists. In Wyoming, WYDOT engineers ranked the following possible factors to accommodate bicyclists as shown in figure 49.

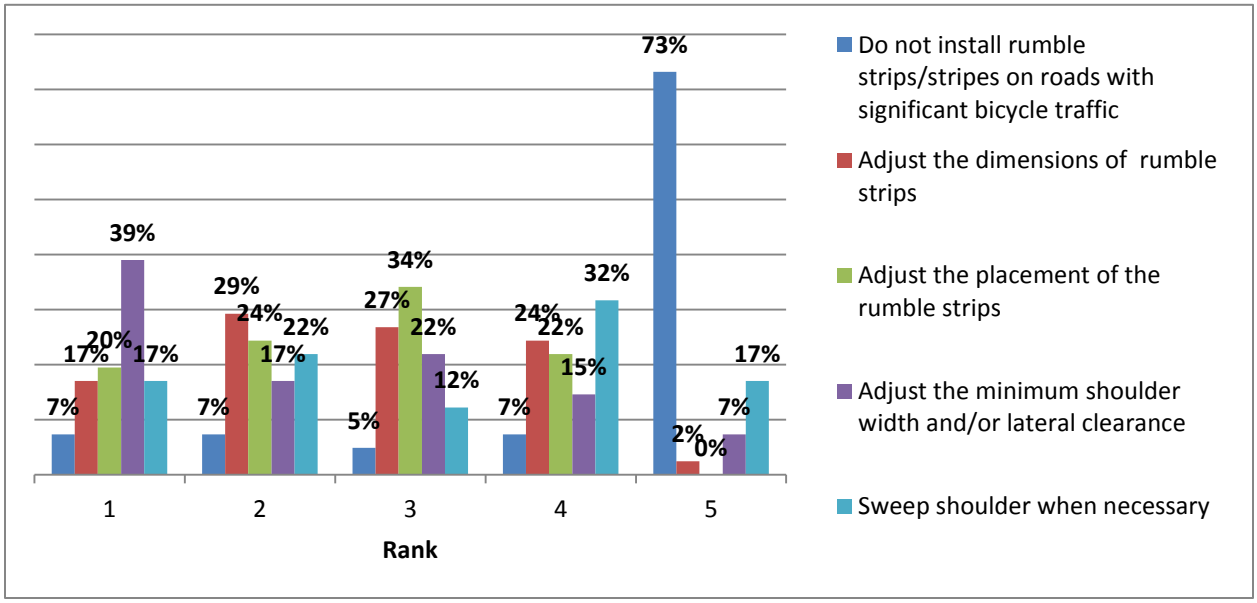

Figure 49: Accommodation of Bicyclists on Roadways with Rumble (WYDOT Survey: Q19).

The main recommendations to accommodate bicyclists: providing wider shoulder, adjust the placement of rumble strips, modify the dimensions of rumble strips, and sweep shoulders more often. It should be noted that WYDOT engineers selected not installing rumble strips as their last choice as shown in figure 49**.** Another way to accommodate bicyclists is reducing the depth of the grooves which will cause fewer vibrations and therefore will be less uncomfortable for the bicyclists while producing enough vibrations for the motorists. WYDOT engineers recommended the use of shallower depth of 3/8 of an inch instead of 1/2 inch with at least 4 feet clear shoulder. Also providing skip pattern by providing gaps every certain length for bicyclists to avoid debris on the shoulder may increase their comfort; about 58 percent recommended 12 feet gaps every 60 feet at minimum. Utilizing other rumble strips shapes such as oval shape in areas with expected high bicycle traffic may alleviate the adverse impact on bicyclists as stated by 58 percent of the respondents.

Providing advanced warning for bicyclists and motorcyclists deemed to be unnecessary from the WYDOT engineers' survey.

Noise

Although the main purpose of using rumble strips is to warn drivers through audible sound and vibrations, the generated noise could be an issue for nearby residents. The solutions proposed by WYDOT engineers are indicated in figure 50. Sixty-three percent supported that rumble strips should not be installed nearby residential areas, while 40 percent considered sinusoidal rumble strips areas as an acceptable alternative nearby residents. Rumble strips were recommended near national parks to warn inattentive drivers.

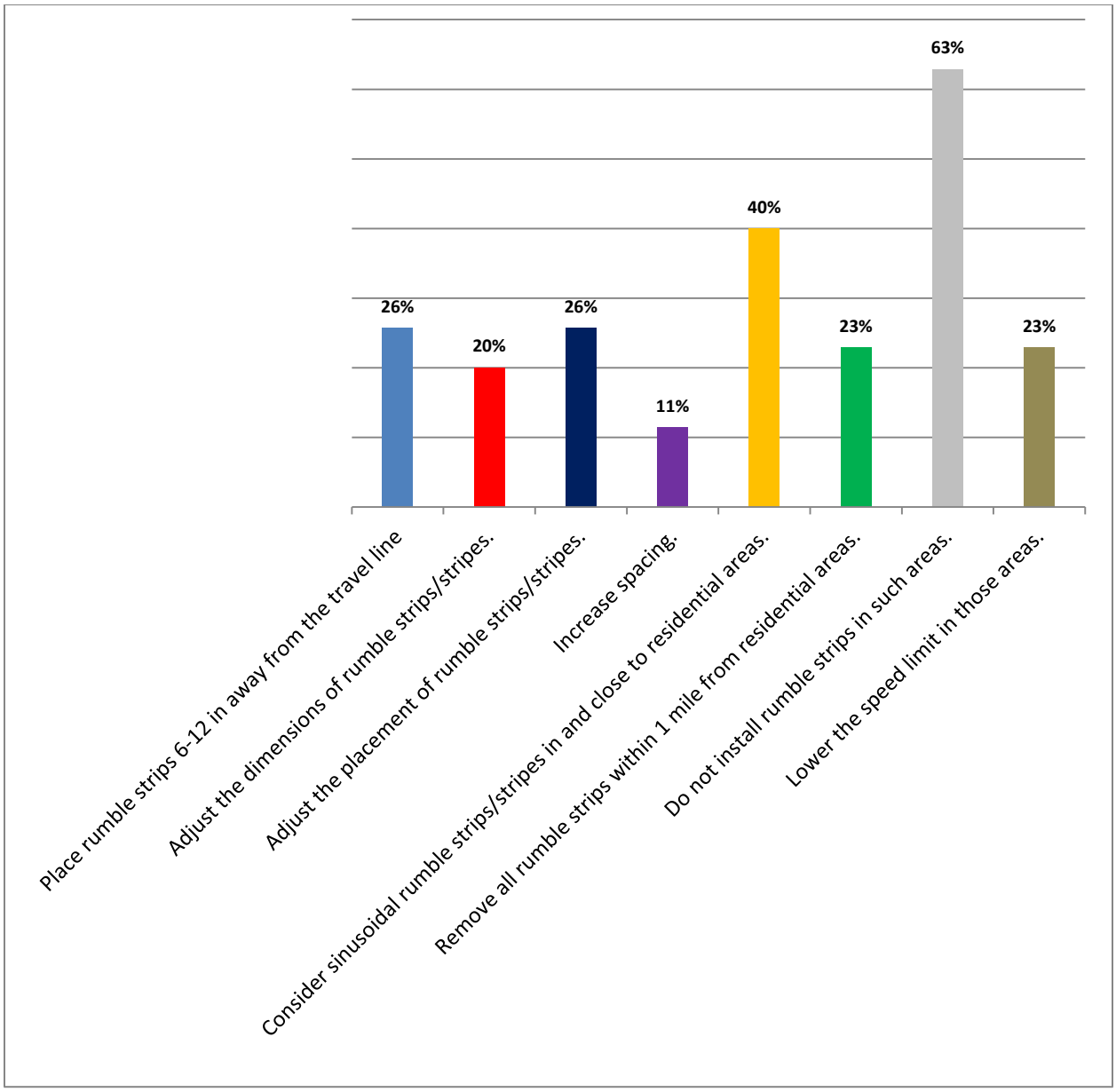

Figure 50 : Recommendations to Address the Noise Issue (WYDOT Survey: Q22).

MOTORCYCLISTS SURVEY

A survey was designed for the motorcyclists to collect their responses about the CLRS. Although, many research indicated that motorcyclists are not affected by the presence of rumble strips, a survey was designed to confirm the results from the literature in this region. Different motorcyclists clubs were contacted in the Mountain West region. Although, online survey questionnaire were sent to more than ten motorcyclists clubs' members inside and outside the

State of Wyoming. Only five responses had been received from the motorcyclists and, hence, results are not discussed in this report.

CHAPTER 4-EXPERT SYSTEM

EXPERT SYSTEM

Expert systems are interactive programs designed to emulate the problem-solving skills of experts. They incorporate judgment, heuristics, intuition, and other expertise to provide knowledgeable advice about a series of tasks. [61] Expert systems have been used in the transportation field for more than 30 years. Recently, researchers are using expert systems rigorously in decision making processes. The knowledge based system is one form of expert system, in which the subject knowledge is held as a set of facts and rules that may be interrogated and manipulated to provide an inferred solution or explanation for a given problem. [62]

EXPERT SYSTEM IN RUMBLE STRIPS/STRIPES

There are many requirements/factors that have to be considered before installing rumble strips/ stripes. Each agency has their own guideline and policy to install rumble strips, which varies from agency to agency. Not all factors are considered the same way in each agency's guideline. There are few agencies which consider ADT, speed limit, and residents in their policies. However, many agencies consider lane width, shoulder width, and bicycle traffic as important factors in their guidelines. The Expert System built for WYDOT is copyrighted, all rights reserved to the State of Wyoming, University of Wyoming, Department of Transportation, 2015.

This Expert System is based on responses from 29 U.S. State transportation agencies, as well as information gathered in earlier surveys, synthesis documents, and responses from 49 WYDOT engineers. This Expert System has been developed to provide guidance of rumble strips/stripes application on interstates, non-freeway divided multilane highways, undivided multilane highways, and two-lane highways in urban and rural settings. This Expert System can be used by DOTs, safety engineers, and district engineers to easily access all the information about rumble strips which will help to make decision on rumble strips installations and designs.

HOW TO USE

The Expert System is split into two main sections; shoulder rumble strips/stripes and centerline rumble strips/stripes as shown in figure 51.

The first flow chart series titled “Shoulder Rumble Strips/Stripes” has six different sections based on areas and road types (figures 52-57). By clicking any of the road types, the user will be taken to a page for the corresponding type of road where all the details about installation criteria and requirements have been listed. Each of these charts are similar in forms and categories. Each chart contains tabs for pavement condition, minimum shoulder width, minimum lane width, speed, heavy bicycle traffic, nearby residents, and Average Daily Traffic (ADT).

Before installing rumble strips in a roadway the factors in the Expert System should be checked. If all the criteria of a certain roadway type falls in the ‘Green’ shaded zone, it is recommended to install shoulder rumble strips in that roadway. For the ‘Yellow’ shaded zone, the recommendation provided in the box should be followed. The district engineers should make the final decision whether to install rumble strips or not. If there are one or more governing criteria in the ‘Red’ area, rumble strips should not be installed, which is a common practice followed by many states and also recommended by WYDOT engineers.

The flow chart titled “Centerline Rumble Strips/Stripes” has a single section based on roadway types, as shown in figure 58. Centerline rumble strips are predominantly used on multi-lane undivided highways and two-lane highways and rural/urban. Lane and shoulder widths, pavement condition, motorcycle traffic, and noise are the important factors governing the application decision of centerline rumble strips.

All the State DOTs and WYDOT survey responses have been referenced in the Expert System, including the information from the NCHRP Report 641. When a survey response is clicked, it will take the user to the survey results gathered for that question. When a state’s name is clicked, it will take the user to the actual pages of that state’s guideline/policy from which the information was extracted. For better accessibility, only important pages related to the requirements have been included in the report. Complete references can be checked via the blue URL hyperlinks provided at the end of each page.

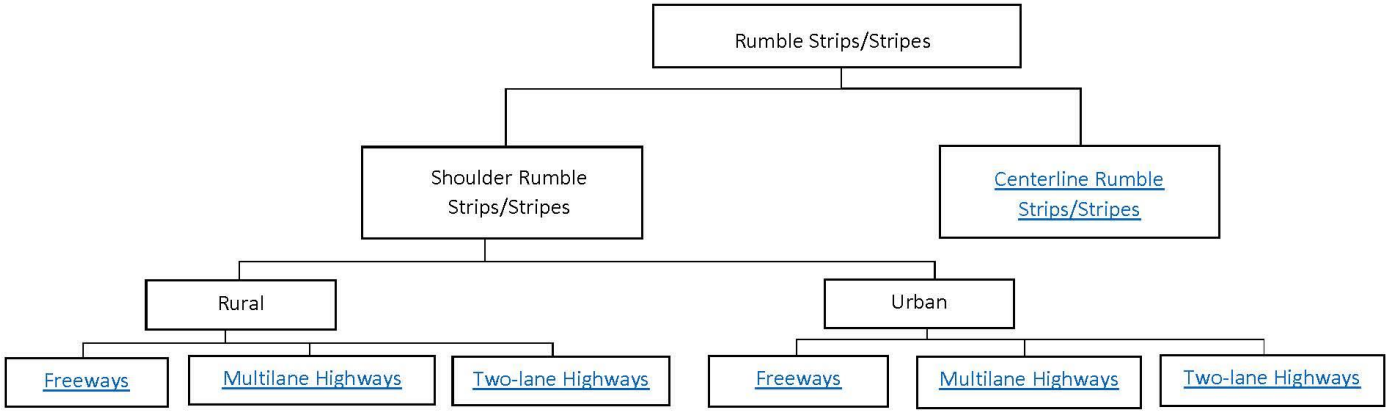

Figure 51: Expert System for Rumble Strips/Stripes

SHOULDER RUMBLE STRIPS/STRIPES

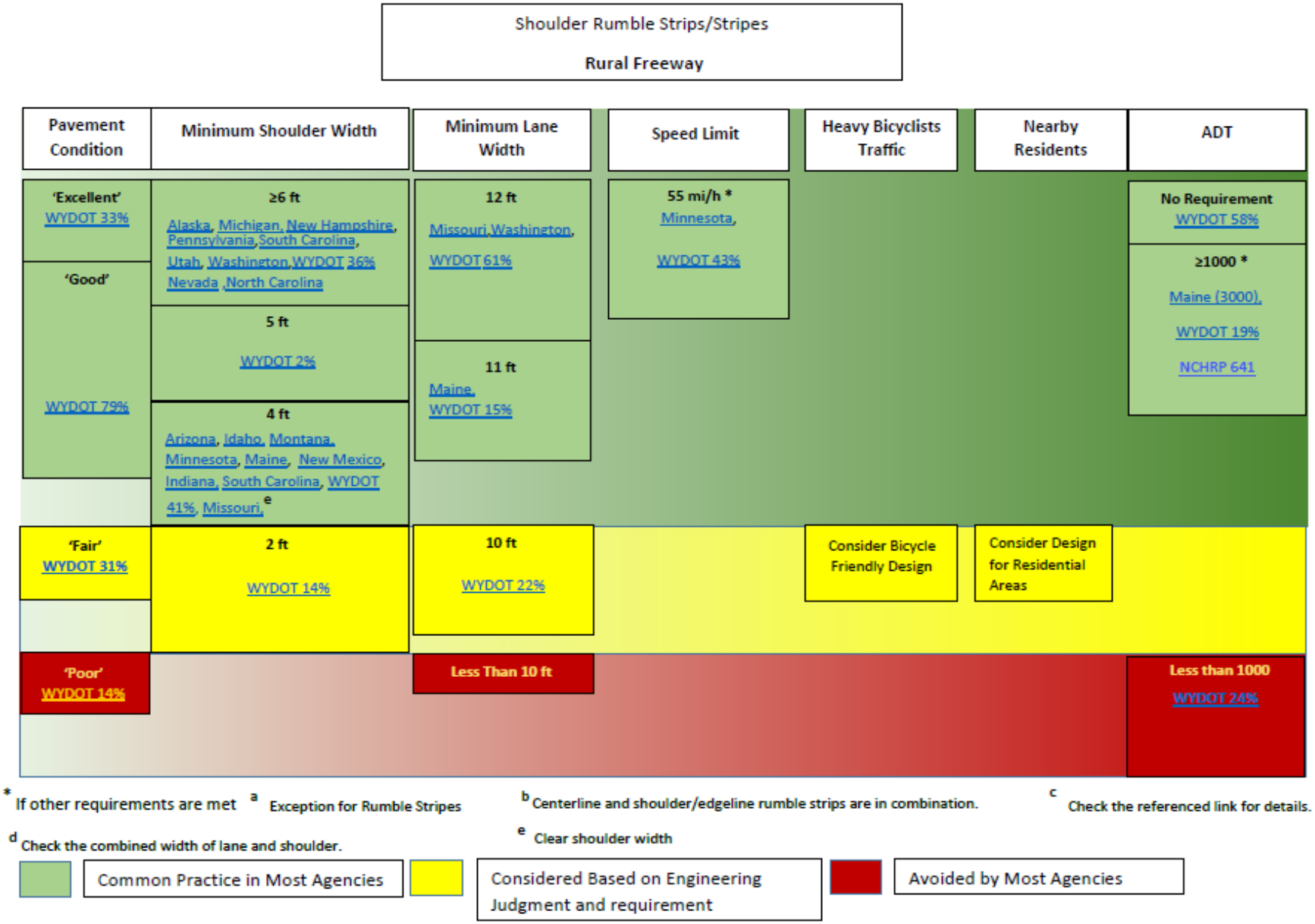

Figure 52: SRS Expert System for Rural Freeway

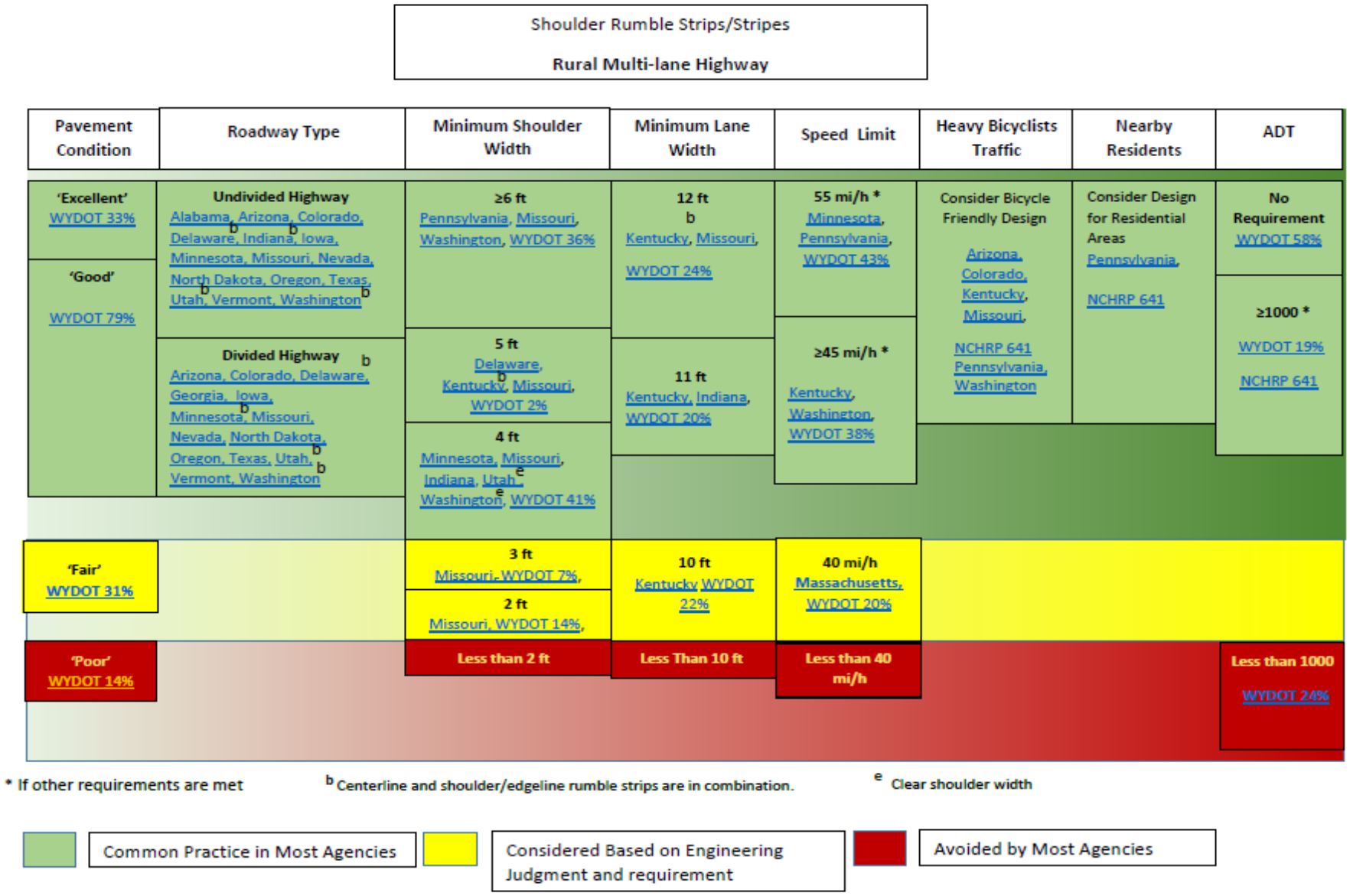

Figure 53: SRS Expert System for Rural Multilane Highway

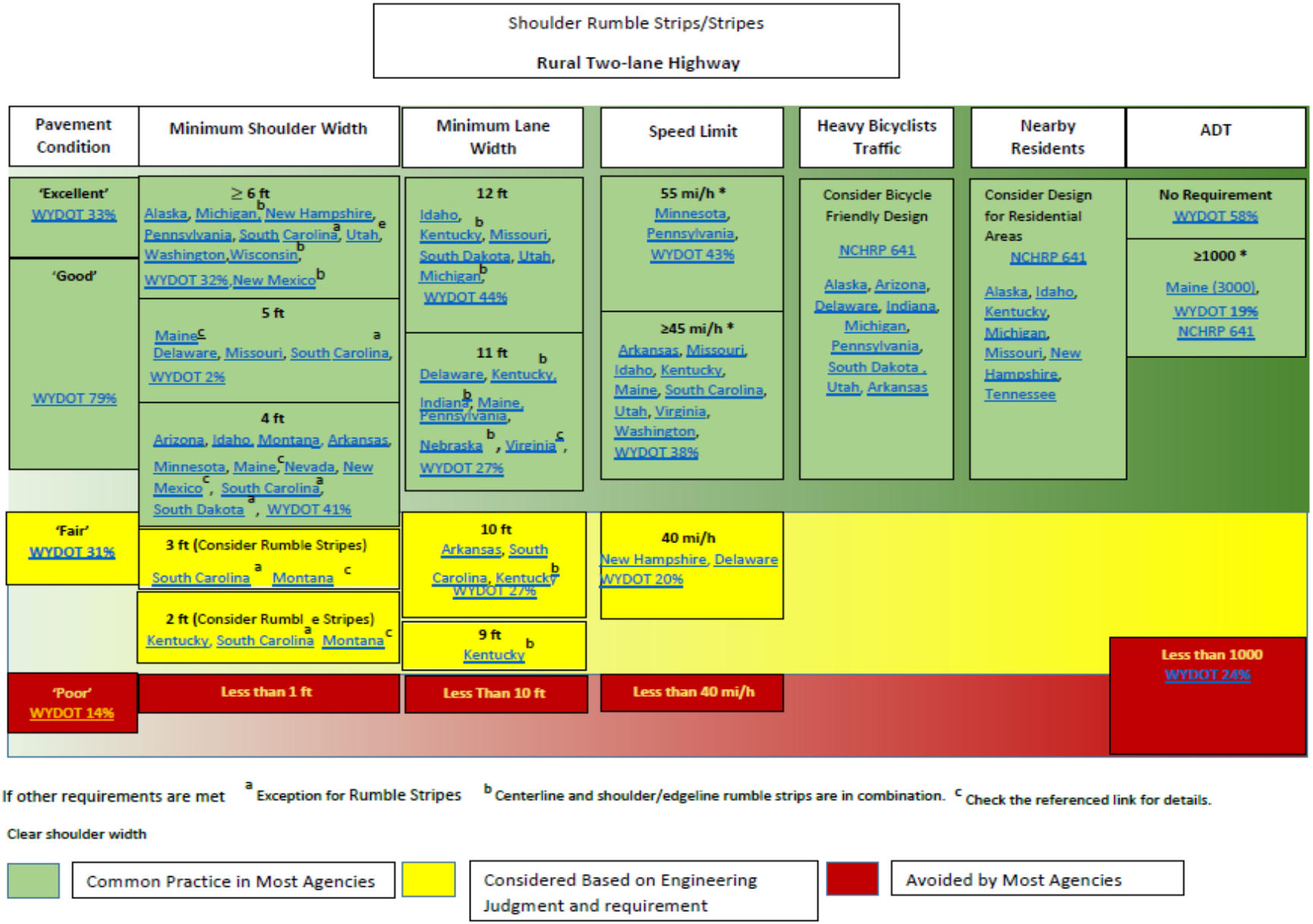

Figure 54: SRS Expert System for Rural Two-lane Highway

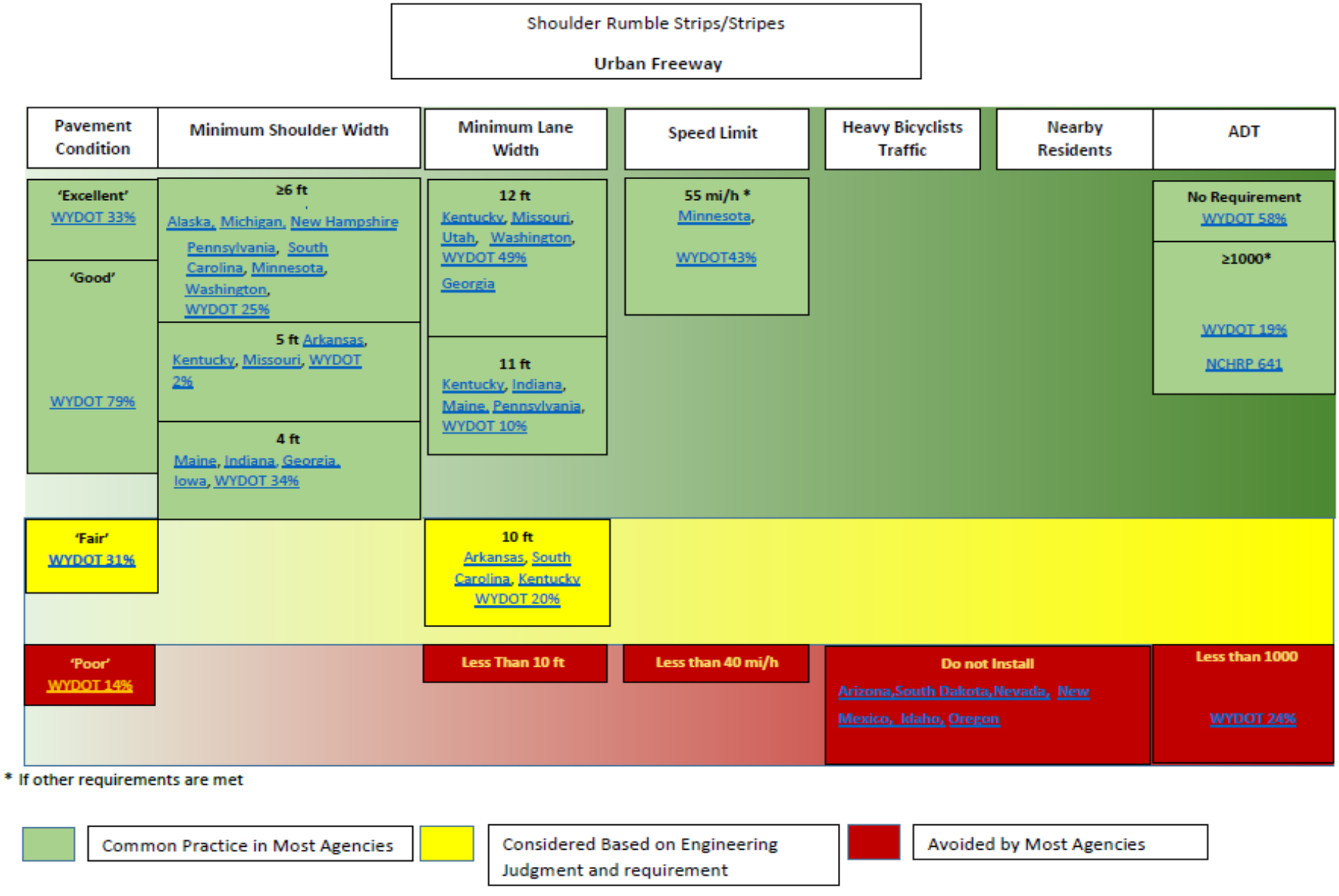

Figure 55: SRS Expert System for Urban Freeway

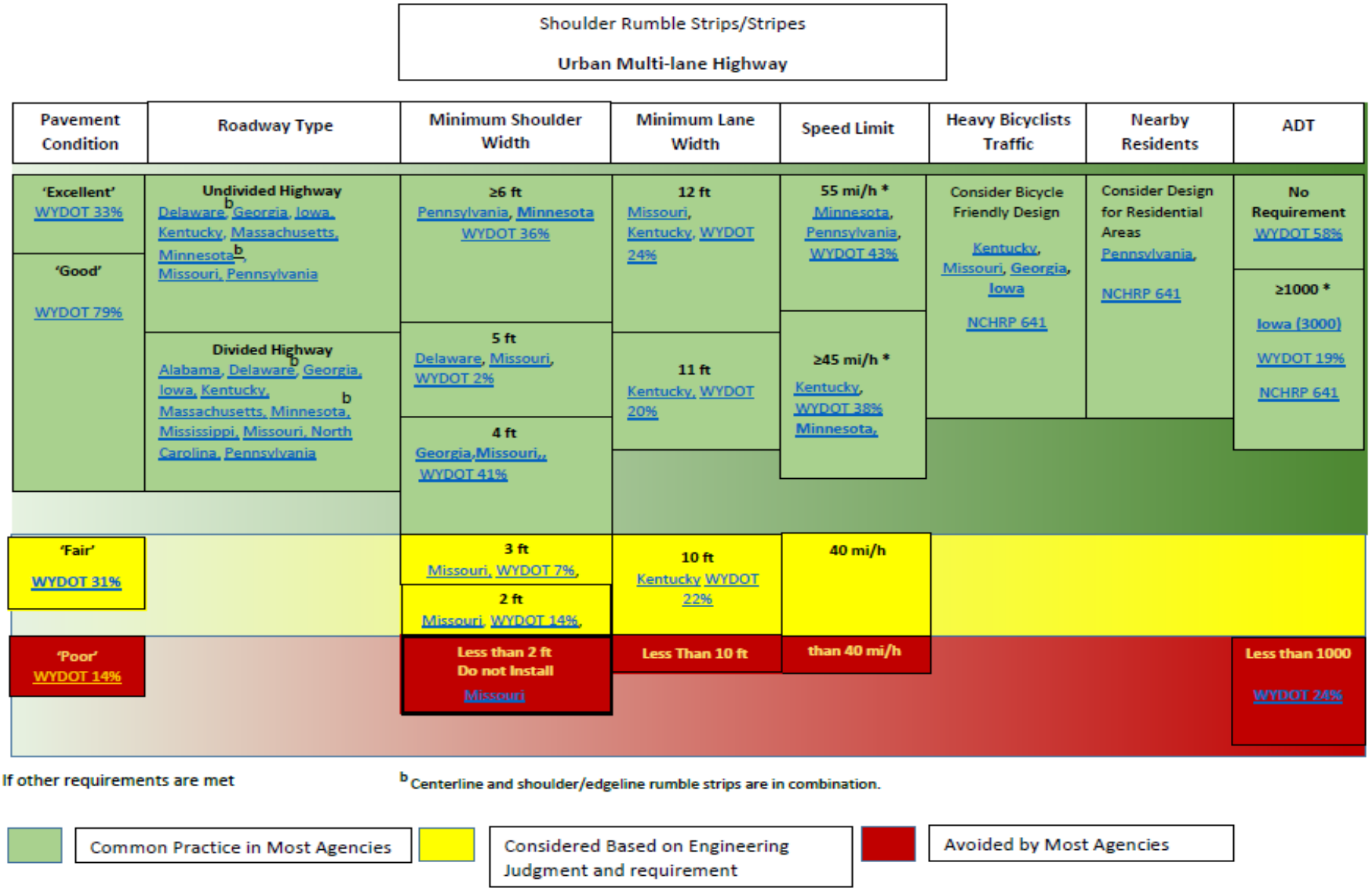

Figure 56: SRS Expert System for Urban Multilane Highway

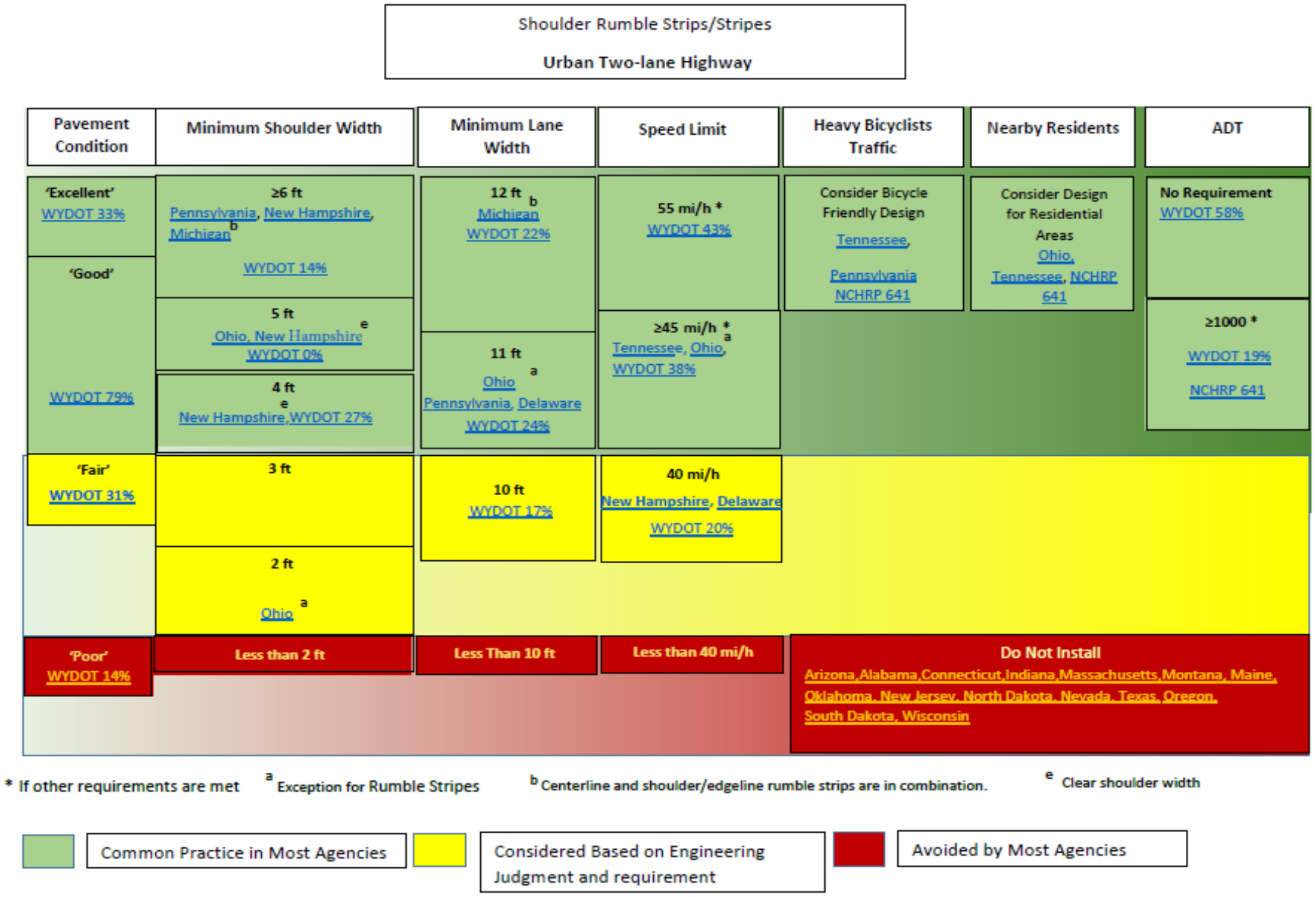

Figure 57: SRS Expert System for Urban Two-lane Highway

CENTERLINE RUMBLE STRIPS/STRIPES

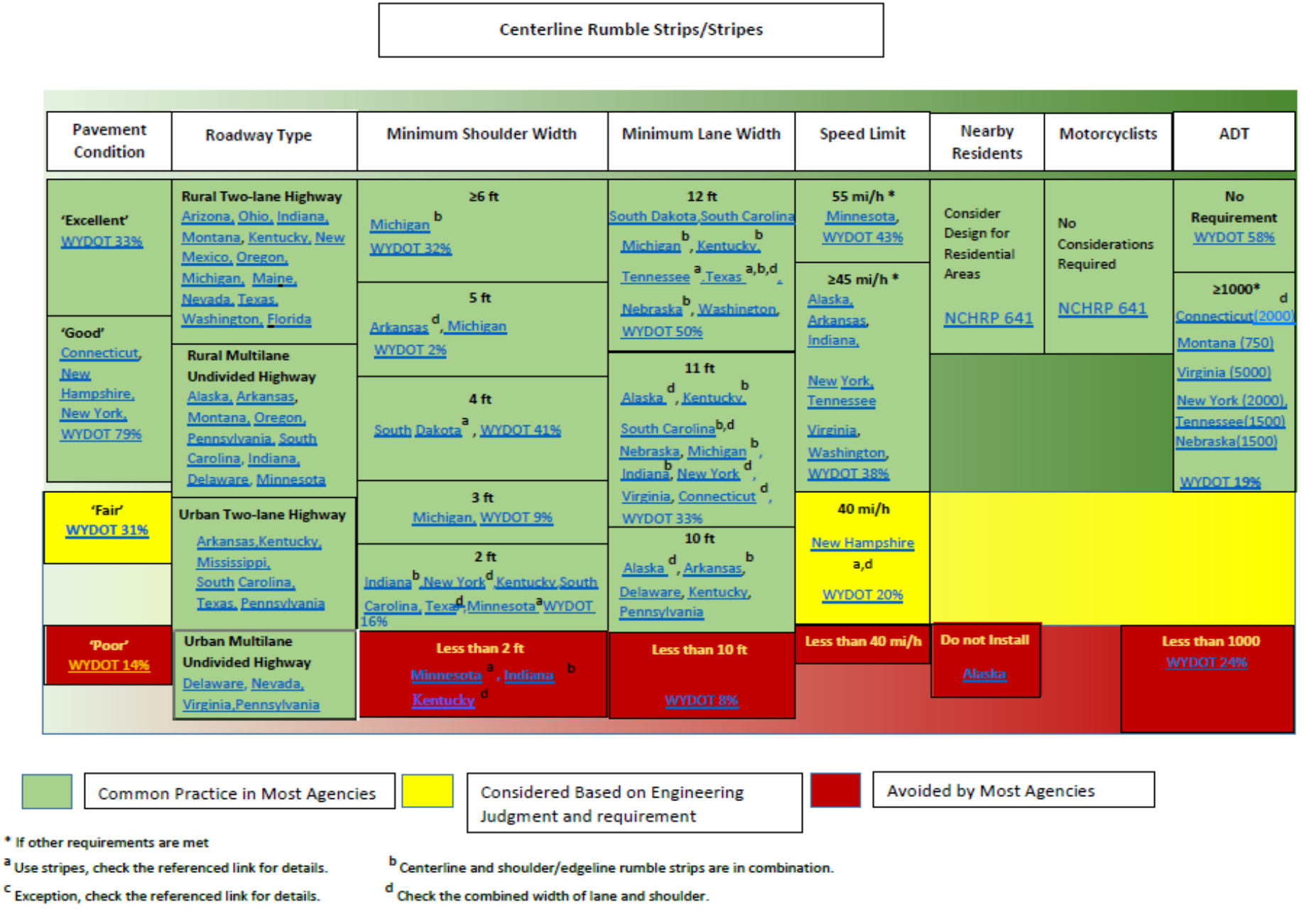

Figure 58: Expert System for Centerline Rumble Strips/Stripes

CHAPTER 5-CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

The systematic implementation of a low-cost improvement, such as shoulder and centerline rumble strips, might be the key to significantly reducing crashes and fatalities. This study was conducted to support Wyoming DOT in developing an effective policy of shoulder and centerline rumble strips/stripes. The new policy will enhance motor vehicle safety while accommodating all road users. A thorough review of the literature and multiple survey questionnaires were conducted to enrich the body of knowledge about rumble strips practices in the U.S. Information was gathered from different road users and nearby residents about their concerns and preferences of rumble strips in the State of Wyoming. Thirty State DOTs responded to the survey questionnaire of which eleven State DOTs provided additional information on their rumble strips/stripes guideline and provisions to accommodate other road users and nearby residents. A total of forty-five engineers from WYDOT participated in this study through an online survey. A total of fifty-seven bicyclists, five motorcyclists, and fifty nearby residents provided their feedback through different survey approaches; mail out, interactive door to door, and online survey questionnaires. Moreover, several issues regarding the use of rumble strips/stripes including; construction, maintenance, and noise were discussed in this report.

The information gathered indicated that many State DOTs have updated, or they are in the process of updating, their rumble strips/stripes policies. Standard milled shoulder rumble strips are widely implemented on all limited-access interstate highways. To increase safety on two-lane highways, combined shoulder and centerline rumble strips are considered by various transportation agencies where speeds are greater than 45 mi/h with substantial traffic volume, or a history of lane departure and head-on crashes. The results from this study indicated that the increase in centerline rumble strips implementation would not affect other non-conventional vehicles such as motorcyclists.

As indicated from the State DOTs survey, accommodating all road users by providing a "Bicycle Friendly Rumble Strips" is considered by many state DOTs. In general, DOTs guidelines do not recommend installing shoulder rumble strips on routes designated as bicycle routes or high bicycle-use areas. Some DOT's policies have mitigated the adverse effect of rumble strips on bicyclists through various remedial measures. Providing 4 feet shoulders, or 5 feet with guardrail as the bare minimum to ensure sufficient space for bicyclists. States such as Alaska and Colorado require a minimum 6 feet shoulder. Florida requires at least 4 feet of continuous clear riding surface where bicyclists are expected. Adjusting rumble strips placement and dimensions such as placing shoulder rumble strips as close to the edge line, and using narrower and shallower designs are other remedial measures used by several states. Providing periodic gaps of at least 12 feet in every 40 or 60 feet are commonly utilized to enhance cyclists' maneuverability to avoid debris along the shoulder, turn, or pass other cyclists. If combined shoulder and centerline rumble strips are to be used on narrow roads with bicycle traffic, a modified lateral width rumble strips is considered to mitigate the adverse effect on vehicle/bicycle interaction. The results from the bicyclists' survey conducted as part of this study, as well as information gathered in earlier surveys, indicated that bicyclists are satisfied with "Bicycle Friendly Rumble Strips" design. It is clear from the survey results that if adequate gaps and shoulder widths are provided, bicyclists can comfortably ride on roads without hitting rumble strips or risk being hit by passing vehicles.

Many states consider nearby residents when installing rumble strips in residential areas by either not installing rumble strips within urban limits or if only warranted by crash experience, a modified shallower depth rumble strips are used. Sometimes, rumble strips are discontinued if there are residents living very close to roadways. Additionally, more gaps are provided between strips in residential areas to reduce the noise levels produced from rumble strips.

Many studies have provided conclusive evidence that centerline rumble strips add no quantifiable risk to motorcyclists. Therefore, most transportation agencies do not consider potential adverse effects for motorcyclists when developing a centerline rumble strips policy.

In addition to the issues presented above, transportation agencies consider other factors such as AADT, posted speed limits, noise, and combined use of rumble strips when developing rumble strips/stripes guidelines to accommodate all roadway users.

Moreover, several concerns regarding the use of rumble strips/stripes including; construction, maintenance, and noise were addressed in this study.

RECOMMENDATIONS

This study demonstrated that despite the fact that rumble strips have been used for many years, there are no standardized practices used in the U.S. A significant number of states are still working on updating their rumble strips policies; their main goal is to enhance motor vehicle safety while accommodating all road users to the highest practical extent. Wyoming DOT has recently developed a general shoulder and centerline rumble strips. The information provided in this report and the companion Expert System will provide the necessary background for WYDOT and other transportation agencies when it comes to update or develop an effective all road users' friendly rumble strips policy. It is recommended that decision makers such as WYDOT district engineers be provided with copies of the Expert System for consultation prior to making decisions on rumble strips/stripes implementation at various locations around the state.

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APPENDIX 1- SURVEY QUESTIONNAIRE FOR DOTS

Survey on Guidelines of Rumble Strips Implementation in Different States

The Wyoming Department of Transportation with the University of Wyoming are currently conducting a study to develop an "Effective Rumble Strips Policy in the State of Wyoming to Accommodate All Road Users."

Please take a few minutes to complete this 22-question survey.

*1. What is your contact info?

Name	
Title	
Agency	
Address	
Phone	
Email	

2. In your agency,who should be contacted about rumble strips/stripes, if we need more information?

Name	
Title	
Address	
Phone	
Email	

3. Does your agency follow the NCHRP guideline* of rumble strip design or you have different specifications for your state?

- ○ Yes, we follow NCHRP Report 641
- ○ Yes, we follow NCHRP Report 641 with some modification.
- ○ No, we do not follow NCHRP Report 641, we have our own guideline.
- ○ No, we do not follow NCHRP Report 641 and, we do not have any guideline.

*NCHRP Report 641 (Guidance for the Design and Application of Shoulder and Centerline Rumble Strips)

Survey on Guidelines of Rumble Strips Implementation in Different States

4. To what types of roadways rumble strips are applied? (Select all that apply)

	Urban Freeway	Rural Freeway	Multilane Highways	Urban Two-lane Highways	Rural Two-lane Highways
Shoulder Rumble Strips	☐	☐	☐	☐	☐
Centerline Rumble Strips	☐	☐	☐	☐	☐
Shoulder Rumble Stripes	☐	☐	☐	☐	☐

5. What condition/s that may prevent installing rumble strips/stripes? (Select all that apply)

- ☐ Area Type (i.e. urban vs. rural)
- ☐ Guardrail
- ☐ Pavement Type
- ☐ Asphalt Layer Thickness and Condition
- ☐ High Bicycle Traffic
- ☐ Motorcyclists
- ☐ Noise
- ☐ Nearby Residents

Comment

6. Have you evaluated the performance of rumble strips in your state?

- ○ Yes
- ○ No
- ○ We are evaluating now.

Comment

Survey on Guidelines of Rumble Strips Implementation in Different States

7. Have you conducted any benefit cost analysis on rumble strips?

- ○ Yes
- ○ No
- ○ The analysis is under processing

Comment

(A) & (B) Shoulder & Centerline Rumble Strips: Rumble strips are grooves or rows of indents in the pavement designed to alert inattentive drivers through noise and vibration to reduce Lane Departure crashes.

(C) Rumble Stripes: Rumble stripes are simply rumble strips cut into the pavement where the edgeline and/or centerline are to be placed. After the rumble strips are ground in, the white or yellow line is marked right over the rumble strips.

8. Does your agency use shoulder rumble strips in combination with centerline rumble strips?

- ○ Yes
- ○ No

9. How do you maintain rumble strips? Please, specify in the box below.

Survey on Guidelines of Rumble Strips Implementation in Different States

10. How frequently you seal rumble strips/stripes?

- Never
- 1-year
- 2-year
- 3-year

11. Do you receive any complaints about shoulder rumble strips from bicyclists?

- Yes
- No

Comment

12. Have you made any provisions to accommodate bicyclists?

- Yes
- No

Comment

13. Have you considered using alternative rumble strips design to accommodate bicyclists?

- Yes
- No

Comment

14. Do you have any considerations for motorcyclists when placing centerline rumble strips?

- Yes
- No

Comment

15. Have you considered using alternative rumble strips design to accommodate motorcyclists?

- Yes
- No

Comment

16. Do you use advanced signs to warn bicyclists and motorcyclists about rumble strips/stripes?

- Yes
- No

Comment

17. Have you received any complaints about the noise of rumble strips from nearby residents?

- Yes
- No

Comment

Survey on Guidelines of Rumble Strips Implementation in Different States

18. Have you considered using alternative rumble strips design to reduce noise?

- Yes
- No

Comment

19. Have you received any crash report for bicyclists/ motorcyclists associated with the rumble strips/stripes?

- Yes
- No

20. Do you take any special measures to increase the night time visibility of rumble stripes?

- Yes
- No

Comment

21. Does your state use transverse or in-line rumble stripes?

- Yes
- No

22. Would you like to receive a summary of the results from this survey?

- Yes
- No

Should you have any questions regarding this survey, please contact:

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Tel: 307-766-5550
Email:mahmed@uwyo.edu

Survey Questionnaire for Wyoming DOT

The Wyoming Department of Transportation with the University of Wyoming are currently conducting a study to develop an "Effective Rumble Strips Policy in the State of Wyoming to Accommodate All Road Users."

Please take a few minutes to complete this 27-question survey.

1. Please, provide your contact information.

Name	
Title	
Phone	
Email	

2. Please rank the features in order of significance directly affecting the installation considerations of rumble strips/stripes?

	Roadway Classification
	Area Type (i.e. urban vs. rural)
	Lane Departure Crash History
	Traffic Volume (ADT)
	Speed
	Shoulder Width
	Lateral Clearance
	Guardrail
	Pavement Type
	Asphalt Layer Thickness
	Pavement Condition
	Bicyclists
	Motorcyclists
	Noise

Survey Questionnaire for Wyoming DOT

(A) & (B) Shoulder & Centerline Rumble Strips: Rumble strips are grooves or rows of indents in the pavement designed to alert inattentive drivers through noise and vibration in order to reduce lane departure crashes.

(C) Rumble Stripes: Rumble stripes are simply rumble strips cut into the pavement where the edgeline and/or centerline are to be placed. After the rumble strips are ground in, a white or yellow line is marked right over the rumble strips.

3. What should be the minimum clear shoulder width to install rumble strips (shown in picture A above) to accommodate all roadway users?

	2 ft	3 ft	4 ft	5 ft	6 ft	Do not install
Urban Freeway	○	○	○	○	○	○
Rural Freeway	○	○	○	○	○	○
Multilane Highways	○	○	○	○	○	○
Urban Two-lane Highways	○	○	○	○	○	○
Rural Two-lane Highways	○	○	○	○	○	○

Comment

4. What should be the minimum shoulder width to install rumble stripes (shown in picture C above) to accommodate all roadway users?

	2 ft	3 ft	4 ft	5 ft	6 ft	Do not install
Urban Freeway	○	○	○	○	○	○
Rural Freeway	○	○	○	○	○	○
Multilane Highways	○	○	○	○	○	○
Urban Two-lane Highways	○	○	○	○	○	○
Rural Two-lane Highways	○	○	○	○	○	○

Comment

Survey Questionnaire for Wyoming DOT

5. Which type/s of rumble strips/stripes should be used in different types of roadways? (Select all that apply)

	Rumble Strips	Rumble Stripes
Interstate	☐	☐
Two-lane and Multi-lane Highways	☐	☐

Comment

6. Should there be any minimum speed limit requirement to install rumble strips/stripes? (Select all that apply)

- ☐ 30 mph
- ☐ 35 mph
- ☐ 40 mph
- ☐ 45 mph
- ☐ 50 mph
- ☐ 55 mph

7. What is the recommended minimum thickness of asphalt layer to install rumble strips? (Select all that apply)

- ☐ 2 in
- ☐ 3 in
- ☐ 4 in
- ☐ more than 4 in

Other (please specify)

8. What is the recommended condition of asphalt layer to install rumble strips? (Select all that apply)

- ☐ Poor
- ☐ Fair
- ☐ Good
- ☐ Excellent

Comment

9. Should traffic volume be considered when placing rumble strips/stripes? If yes, what should be the minimum Average Daily Traffic (ADT vehicle per day)

- ○ No requirement
- ○ 100
- ○ 200
- ○ 400
- ○ 1000
- ○ >1000

10. What should be the minimum lane width to install shoulder rumble strips (shown in picture A above)?

	10 ft	11 ft	12 ft	Do not install
Urban Freeway	○	○	○	○
Rural Freeway	○	○	○	○
Multilane Highways	○	○	○	○
Urban Two-lane Highways	○	○	○	○
Rural Two-lane Highways	○	○	○	○

Comment

11. What should be the minimum lane width to install shoulder rumble stripes (shown in picture C above)?

	10 ft	11 ft	12 ft	Do not install
Urban Freeway	○	○	○	○
Rural Freeway	○	○	○	○
Multilane Highways	○	○	○	○
Urban Two-lane Highways	○	○	○	○
Rural Two-lane Highways	○	○	○	○

Comment

12. Please select features or areas where shoulder rumble strips should be discontinued to avoid adverse consequences. (select all that apply)

- ☐ Entrance and exit ramps
- ☐ When turn lanes are provided
- ☐ When lateral clearance is less than required
- ☐ At intersections, driveway and median crossings
- ☐ Near catch basins
- ☐ Near residential areas
- ☐ Near pavement joints
- ☐ Where curb and gutters are installed
- ☐ Guardrail is present

Other (please specify)

13. On what type of roadways should WYDOT install centerline rumble strips? (Select all that apply)

	Sub-urban multilane undivided highways	Sub-urban two lane roads	Rural multilane undivided highways	Rural two lane roads
Roadways with high Average Daily Traffic (ADT)	☐	☐	☐	☐
Roadways with high number of Head-on/Sideswipe Lane Departure Crashes	☐	☐	☐	☐

Other (please specify)

14. What should be the minimum lane width to install centerline rumble strips?

	11 ft	12 ft	13 ft	14 ft	Do not install
Urban Freeway	○	○	○	○	○
Rural Freeway	○	○	○	○	○
Multilane Highways	○	○	○	○	○
Urban Two-lane Highways	○	○	○	○	○
Rural Two-lane Highways	○	○	○	○	○

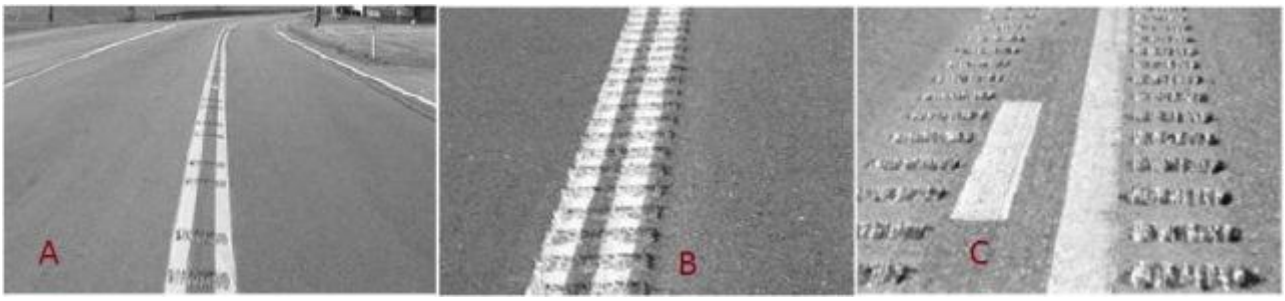
Other (please specify)

15. What should be the minimum lane width to install centerline rumble strips in combination with shoulder rumble strips?

	11 ft	12 ft	13 ft	14 ft	Do not install
Urban Freeway	○	○	○	○	○
Rural Freeway	○	○	○	○	○
Multilane Highways	○	○	○	○	○
Urban Two-lane Highways	○	○	○	○	○
Rural Two-lane Highways	○	○	○	○	○

Other (please specify)

There are three common types of centerline rumble strips used by different agencies.



16. Which type of centerline rumble strips do you recommend to install in Wyoming to accomodate motorcyclists?

- ○ A. Centerline rumble strips within pavement markings.
- ○ B. Centerline rumble strips extend into travel lane.
- ○ C. Centerline rumble strips on either side of pavement markings.

17. In your opinion, how motorcyclists can be accommodated in the roadway with centerline rumble stripes? (Select all that apply)

- ☐ Wide the lane width
- ☐ Decrease the depth (less than 1/2 in)
- ☐ Do not install rumble strips in passing zone
- ☐ Increase the spacing

Other (please specify)

18. Please select features or areas where centerline rumble strips should be discontinued to avoid adverse consequences. (Select all that apply)

- ☐ Intersections and driveways.
- ☐ Passing zones.
- ☐ Structures. (e.g. Bridges)
- ☐ Residential areas.

Other (Please specify)

19. Please rank, what can be done to accommodate bicyclists on roadways with rumble strips/stripes?

	Sweep shoulder when necessary.
	Adjust the minimum shoulder width and/or lateral clearance.
	Adjust the placement of the rumble strips.
	Adjust the dimensions of rumble strips.
	Do not install rumble strips/stripes on roads with significant bicycle traffic.

20. What is the recommended bicycle gap that should be provided to make a safe exit without striking the shoulder rumble strips/stripes?
(The present practice of WYDOT is 12 ft gaps in 48 ft cycles)

- ○ 10 ft gaps in 40 ft cycles
- ○ 12 ft gaps in 48 ft cycles
- ○ 12 ft gaps in 60 ft cycles

Other (please specify)

21. To accommodate bicyclists,what are your recommendations in terms of the dimensions? (Select all that apply)

- ☐ Depth (3/8 in instead of 1/2 in)
- ☐ Spacing (12 in instead of 5 in)
- ☐ Width (5 in instead of 7 in)
- ☐ Narrow length (less than 12-16 in)
- ☐ Non-zero offset (12 in from edge) with at least 4 ft lateral clearance

Other (please specify)

There are three styles of rumble strips design.

Rectangular strips: This is the most common type used by many states.It increases external noise level by 5-19 decibels and increase noise levels inside vehicles by 5-15 decibels.It is the most effective type to reduce crashes.However, it has the most adverse effect on bicyclists and environment (noise).

Oval strips: The most convenient for bicyclists. They also produce same level of noise of rectangular strips.They are less effective than rectangular strips in reducing crashes.

Sinusoidal strips: This type of rumble strips is quietest in terms of noise. They produce 3-7 decibels less sound than rectangular strips.

22. Noise could be an issue for nearby residents to rumble strips/stripes, What can be done in this regard? (Select all that apply)

- ☐ Adjust the dimensions of rumble strips/stripes.
- ☐ Lower the speed limit in those areas.
- ☐ Consider sinusoidal rumble strips/stripes in and close to residential areas.
- ☐ Increase spacing.
- ☐ Remove all rumble strips within 1 mile from residential areas.
- ☐ Do not install rumble strips in such areas.
- ☐ Adjust the placement of rumble strips/stripes.
- ☐ Place rumble strips 6-12 in away from the travel lane.

Other (please specify)

23. Would you recommend installation of rumble strips/stripes close to national parks?

- ○ Yes
- ○ No

24. Would you recommend installing the sinusoidal shoulder rumble strips nearby residents and close to national parks?

- ○ Yes
- ○ No

25. If a high bicycle traffic location, would you recommend installing oval shape strips instead of rectangular strips?

- ○ Yes
- ○ No

26. Should advanced signs to warn bicyclists and motorcyclists about rumble strips/stripes be added? How far in advance?

- ○ 300 ft
- ○ 500 ft
- ○ 1 mile

Other (please specify)

Survey Questionnaire for Wyoming DOT

27. The current practice of WYDOT is not to place Rumble strips/stripes at locations where major surfacing work is anticipated within the next three years. To reduce lane departure crashes in Wyoming, this policy should be updated to:

- ○ 0-year
- ○ 1-year
- ○ 2-year
- ○ Keep at 3-year

Comment

Should you have any questions regarding this survey, please contact:

Khaled Ksaiabti, Ph.D., PE or Mohamed M. Ahmed, Ph.D.
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College of Engineering and Applied Science
University of Wyoming
Laramie, Wyoming 82071
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Email:khaled@uwyo.edu or mahmed@uwyo.edu

.....To submit please hit the Done button, you will not be able to edit your responses once submitted!.....
.....Thank you for your participation.....

APPENDIX 3- SURVEY QUESTIONNAIRE FOR BICYCLISTS

Survey Questionnaire for Bicyclists

Objective of the Survey:

Researchers at the University of Wyoming (UW) are currently working on a Wyoming Department of Transportation (WYDOT) sponsored project intended to develop an effective shoulder and centerline rumble strips/stripes policy to accommodate all roadway users.To help us achieve this goal, we would like to invite you to complete this survey. All answers are anonymous. There are no anticipated risks or direct benefits to you if you decide to participate. There is no penalty if you decide not to participate. You can end your participation at anytime and you do not have to answer any questions that you do not want to answer. The survey will take only about 5-8 minutes of your time.

1. Are you 18 years old or older? (Yes/No) (If "No" terminate the survey).

- ○ Yes
- ○ No

2. Do you ride bicycles, If "yes", please begin to answer survey questions.(If "No" terminate the survey)

- ○ Yes
- ○ No

3. How long have you been riding bicycles?

- ○ Less than 1 year
- ○ 2-3 years
- ○ 4-5 years
- ○ 6-10 years
- ○ 11-20 years
- ○ Over 20 years

4. What kind of bicycle(s) do you usually ride? (Select all that apply)

- ☐ Mountain bike
- ☐ Road bike
- ☐ Hybrid
- ☐ Touring bike
- ☐ Cruiser
- ☐ Recumbent
- ☐ Dirt bike

Survey Questionnaire for Bicyclists

5. How frequently do you ride your bike?

- ○ Every day
- ○ Weekdays only
- ○ Weekends only
- ○ Some weekdays and weekends
- ○ Infrequently

6. Approximately, how many miles do you ride your bike per week?

- ○ Less than 10 miles
- ○ Between 10 and 50 miles
- ○ Between 50 and 100 miles
- ○ Between 100 and 200 miles
- ○ More than 200 miles

7. Where do you ride mostly? (Select all that apply)

- ☐ State highways
- ☐ Country or county roads
- ☐ Bike paths or trails
- ☐ City streets
- ☐ Sidewalks
- ☐ Dirt Roads
- ☐ Others

Rumble strips are grooves or rows of indents in the pavement designed to alert inattentive drivers through noise and vibration in order to reduce lane departure crashes.

Survey Questionnaire for Bicyclists

A. Continuous Shoulder Rumble Strips
B. Intermittent Shoulder Rumble Strips

8. Do you consider the presence of shoulder rumble strips when selecting a route?

- Yes
- No

9. Have you ever run over (come in contact) with a shoulder rumble strips?

- Yes
- No

10. What was your reaction the first time you have driven over shoulder rumble strips?

11. Do you feel uncomfortable riding on roadways with shoulder rumble strips?

- Yes
- No

12. As a bicyclist, have you ever had any accidents because of shoulder rumble strips?

- Yes
- No

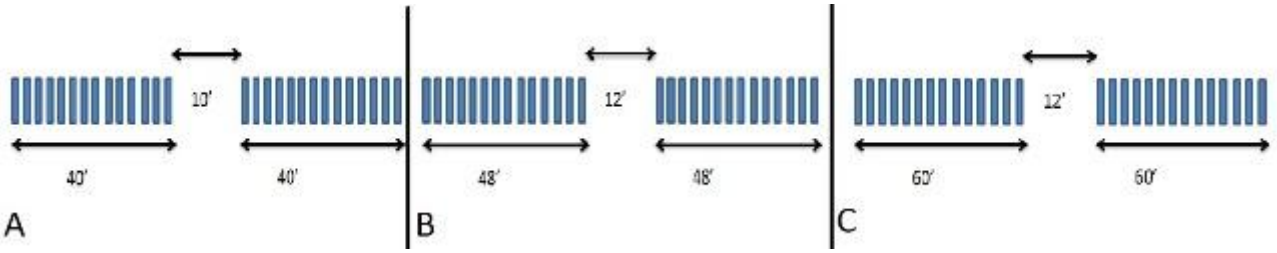
If yes, (please specify)

Survey Questionnaire for Bicyclists

13. In your opinion, in the presence of shoulder rumble strips what is the minimum clear shoulder width that should be provided for safe bicycling?

- 3 ft
- 4 ft
- 5 ft
- 6 ft
- More than 6 ft

The below figures illustrate 3 different patterns of intermittent rumble strips. The recurring short gaps in the continuous rumble strips pattern are provided to allow for ease of movement of bicyclists from one side of the rumble strips to the other.



14. In your opinion, what is the recommended bicycle gap that should be provided to make a safe exit without striking the shoulder rumble strips?
(The present practice of WYDOT is 12 ft gaps in 48 ft cycles)

- 10 ft gaps in 40 ft cycles (Figure A)
- 12 ft gaps in 48 ft cycles (Figure B)
- 12 ft gaps in 60 ft cycles (Figure C)

Other (please specify)

15. Should bicyclists be warned about the presence of shoulder rumble strips?

- Yes
- No

Survey Questionnaire for Bicyclists

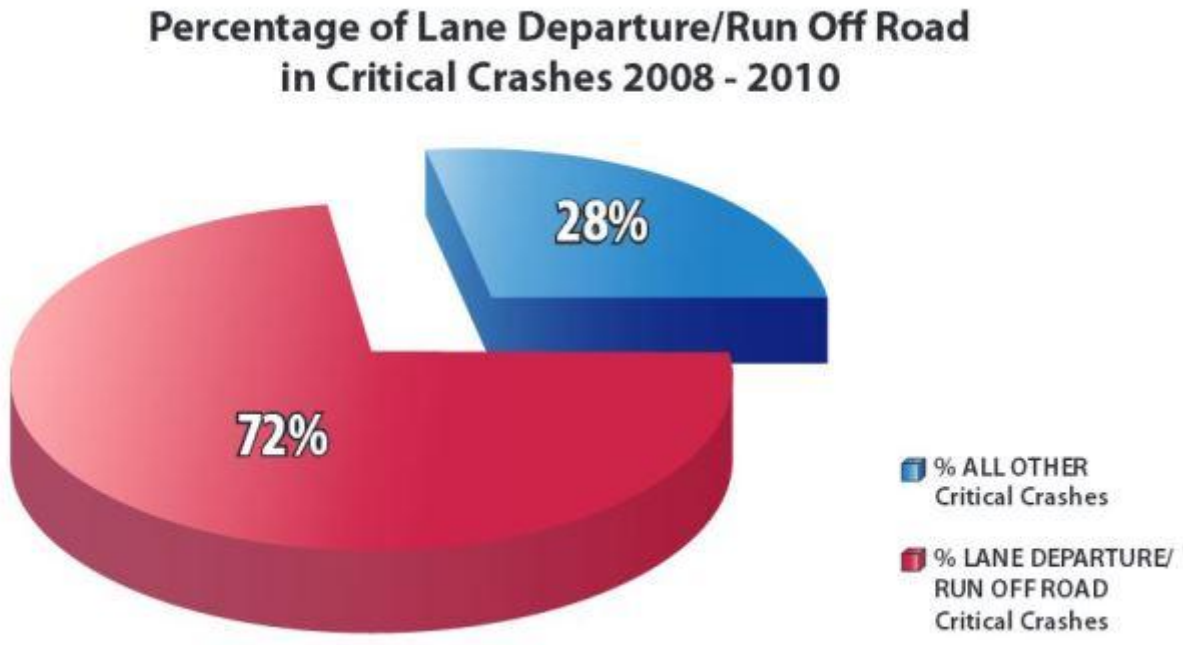
Rumble Strips Warning Sign

16. Please rank, what can be done to accommodate bicyclists on roadways with shoulder rumble strips?

	Do not install shoulder rumble strips on roads with significant bicycle traffic
	Use narrower shoulder rumble strips
	Place shoulder rumble strips closer to the traffic lane.
	Sweep shoulders more frequently
	Increase clear shoulder width

Survey Questionnaire for Bicyclists

The Wyoming Strategic Highway Safety Plan 2012 indicated that lane departure crashes comprised 72% of all sever crashes for the years 2008 – 2010.
Rumble strips/ stripes are used by many states as a relatively low cost proven safety countermeasure to reduce or prevent lane departure crashes through providing a vibrotactile or audible warning to inattentive motorists.



17. As a driver, do you believe shoulder rumble strips enhance public driving safety?

- Yes
- No

18. As a bicyclist, will you accept an increase in shoulder rumble strips implementation in the state of Wyoming knowing that they are effective in saving lives?

- Yes
- No

The following section provides general questions that will be extremely valuable to perform a sound analysis, these questions are very general and will not identify participants' personal information. Your Information is kept strictly confidential and secure, and will not be shared with any third parties.

19. What is your gender?

- Male
- Female

Survey Questionnaire for Bicyclists

20. Which of the following best describes your age (in years)?

- 18-25
- 26-35
- 36-50
- 51-65
- over 65

21. What is the highest level of education that you have completed?

- Graduate school or higher
- College degree
- Some college
- High school
- Did not graduate from high school

22. In which town/city do you live?

23. Do you have any additional comments or suggestions regarding rumble strips?

Should you have any questions regarding this survey, please contact:

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College of Engineering and Applied Science
University of Wyoming
Laramie, Wyoming 82071
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Email: mahmed@uwyo.edu

.....Thank you for your participation.....

APPENDIX 4- SURVEY QUESTIONNAIRE FOR MOTORCYCLISTS

Survey Questionnaire for Motorcyclists

Objective of the survey

Researchers at the University of Wyoming (UW) are currently working on a Wyoming Department of Transportation (WYDOT) sponsored project intended to develop an effective shoulder and centerline rumble strips/stripes policy to accommodate all roadway users.To help us achieve this goal, we would like to invite you to complete this survey. All answers are anonymous. There are no anticipated risks or direct benefits to you if you decide to participate. There is no penalty if you decide not to participate. You can end your participation at anytime and you do not have to answer any questions that you do not want to answer. The survey will take only about 5 minutes of your time.

1. Are you 18 years old or older? (Yes/No) (If "No" terminate the survey).

- ○ Yes
- ○ No

2. Do you ride a motorcycle, If "yes", please begin to answer survey questions.(If "No" terminate the survey)

- ○ Yes
- ○ No

3. What kind of motorcycle do you usually ride?

- ○ Standard
- ○ Sports bike
- ○ Cruiser
- ○ Touring bikes
- ○ Three wheel motorcycles
- ○ Off Road
- ○ Others

4. For how long have you been riding motorcycles?

- ○ Less than 1 year
- ○ 1-2 years
- ○ 3-5 years
- ○ 6-9 years
- ○ 10-20 years
- ○ Over 20 years

Survey Questionnaire for Motorcyclists

5. How frequently do you ride your motorcycle?

- ○ Everyday
- ○ Weekends only
- ○ Week days only
- ○ Some weekdays and weekends
- ○ Infrequent

6. Approximately, how many miles do you drive your motorcycle per year?

- ○ Less than 500 miles
- ○ Between 500 and 1000 miles
- ○ Between 1000 and 5000
- ○ More than 5000

7. Where do you ride mostly? (Select all that apply)

- ☐ Interstate
- ☐ State highways
- ☐ Two-way Two-lane roadways
- ☐ City roads
- ☐ Dirt roads
- ☐ Others

Rumble strips are grooves or rows of indents in the pavement designed to alert inattentive drivers through noise and vibration in order to reduce lane departure crashes.

Survey Questionnaire for Motorcyclists

A. Shoulder Rumble Strips: Shoulder Rumble Strips are an effective means of preventing run-off-the-road crashes. They are primarily used to warn drivers when they have drifted from their lane.

B. Centerline Rumble Strips: Centerline Rumble Strips are an effective countermeasure to prevent head-on collisions and opposite-direction sideswipes. Centerline Rumble Strips are primarily used to warn drivers whose vehicles are crossing centerlines of two-lane, two-way roads.

8. Have you ever run over (come in contact) with a centerline rumble strips?

- ○ Yes
- ○ No

9. Did the centerline rumble strips cause any difficulties when you crossed them on two-way roadways?

- ○ Yes
- ○ No

Comments

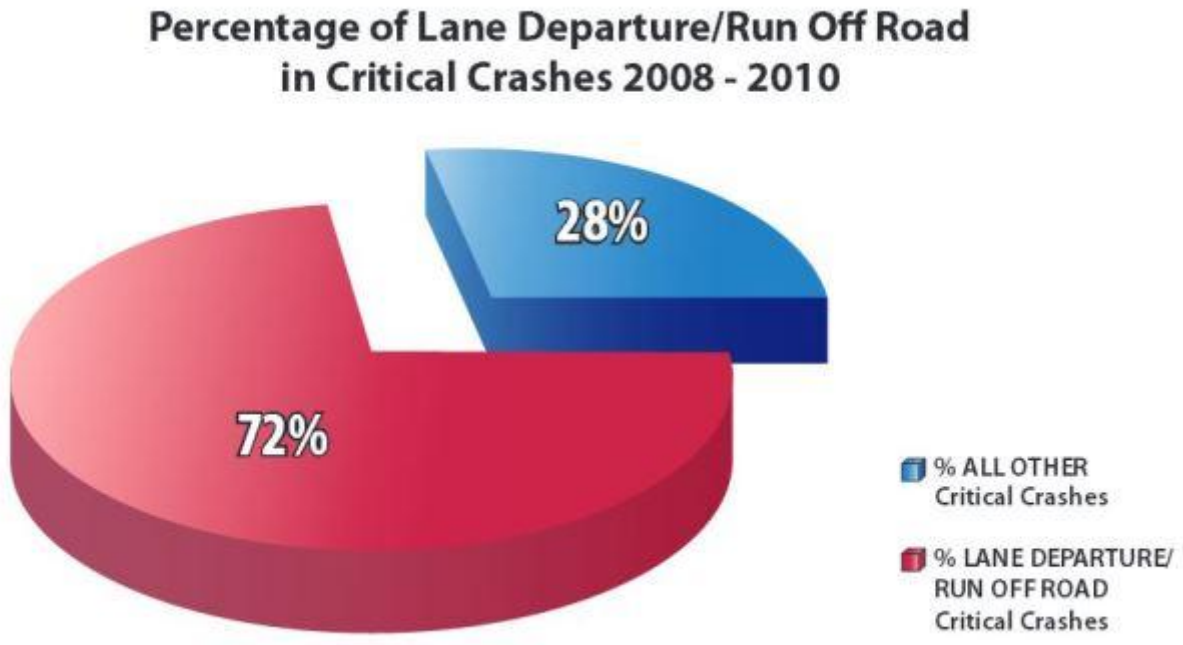
10. Have you ever lost control because of centerline rumble strips?

- ○ Yes
- ○ No

If yes, (please specify)

Survey Questionnaire for Motorcyclists

The Wyoming Strategic Highway Safety Plan 2012 indicated that lane departure crashes comprised 72% of all sever crashes for the years 2008 – 2010.
Rumble strips/ stripes are used by many states as a relatively low cost proven safety countermeasure to reduce or prevent lane departure crashes through providing a vibrotactile or audible warning to inattentive motorists.



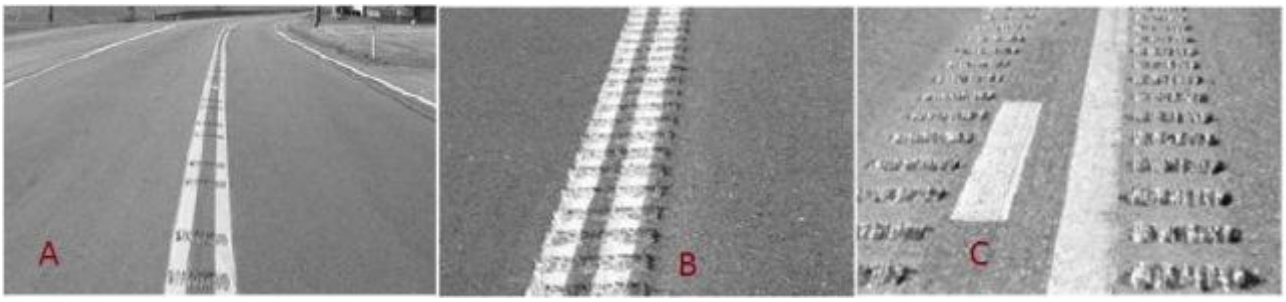
11. Do you believe centerline rumble strips enhance public driving safety?

- Yes
- No

12. In your opinion, Which type of centerline rumble strips would be suitable in Wyoming to accommodate motorcyclists?

- A. Centerline rumble strips within pavement markings.
- B. Centerline rumble strips extend into travel lane.
- C. Centerline rumble strips on either side of pavement markings.

There are three common types of centerline rumble strips used by different agencies.



13. In your opinion, how can motorcyclists be accommodated in roadways with centerline rumble stripes? (Select all that apply)

- ☐ Widen the lane width
- ☐ Decrease the depth (less than 1/2 in)
- ☐ Do not install rumble strips in passing zone
- ☐ Provide longer gaps without rumble strips

Other (please specify)

14. Should centerline rumble strips be discontinued at passing zones?

- ○ Yes
- ○ No

Other (please specify)

15. Should motorcyclists be warned about the presence of centerline rumble strips?

- ○ Yes
- ○ No

Survey Questionnaire for Motorcyclists

Rumble Strips Warning Sign

16. As a motorcyclist, Will you accept centerline rumble strips knowing that they are effective in saving lives?

- Yes
- No

The following section provides general questions that will be extremely valuable to perform a sound analysis, these questions are very general and will not identify participants' personal information. Your Information is kept strictly confidential and secure, and will not be shared with any third parties.

17. What is your gender?

- Male
- Female

18. Which of the following best describes your age (in years)?

- 18-25
- 26-35
- 36-50
- 51-65
- over 65

19. What is the highest level of education that you have completed?

- Graduate school or higher
- College degree
- Some college
- High school
- Did not graduate from high school

Survey Questionnaire for Motorcyclists

20. Do you have any additional comments or suggestions regarding centerline rumble strips?

Should you have any questions regarding this survey, please contact:

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Civil and Architectural Engineering
College of Engineering and Applied Science
University of Wyoming
Laramie, Wyoming 82071
Tel: 307-766-5550
Email: mahmed@uwyo.edu

.....Thank you for your participation.....

APPENDIX 5- SURVEY QUESTIONS FOR NEARBY RESIDENTS

Survey Questionnaire for Nearby Residents

1. Are you 18 years old or older? (Yes/No)

- Yes
- No

2. Which type of rumble strips is installed close to your residence?

- A. Continuous Shoulder Rumble Strips:
- B. Intermittent Shoulder Rumble Strips:

3. How far is your residence from rumble strips?

- Within 100 ft
- 100-300 ft
- 300-500 ft
- 500-1000 ft
- More than 1 mile

4. Can you hear the noise from your residence when a driver crosses over the nearby rumble strips?

- Yes
- No

5. How often can you hear the noise? (select only one)

- Less than once a day
- 1-5 times a day
- 5-10 times a day
- More than 10 times daily

Survey Questionnaire for Nearby Residents

6. What time(s) of the day do you hear the noise most? (You may select multiple answers)

- [ ] All the day
- [ ] Early morning
- [ ] Morning
- [ ] Afternoon
- [ ] Evening
- [ ] Late night
- [ ] Midnight

Other (please specify)

7. What is the level of noise you hear in your residence when a vehicle run over rumble strips? (select only one)

- ○ High
- ○ Moderate
- ○ Low

Other

8. External noise produced from rumble strips ____? (Select only one)

- ○ Acceptable
- ○ Not acceptable
- ○ No opinion

9. What is your preference about installing rumble strips close to residential areas? (Select only one)

- Do not use
- Limit the use
- Use quieter design
- Remove the existing
- Install rumble strips. but. lower the speed limit
- Use them to save drivers' lives
- No preference

10. Will you tolerate the noise from rumble strips knowing that it saves lives?

- Yes
- No

11. How long have you been driving? (Select only one)

- Do not drive
- Less than 1 year
- 1-5 year
- 5-10 year
- 10-15 year
- More than 15 year

12. Have you ever run over (come in contact) with a shoulder rumble strips?

- Yes
- No

13. What was your reaction the first time you driven over rumble strips? (Please, write in the comment box)

14. Do you believe rumble strips enhance public driving safety?

- Yes
- No

15. Do you think rumble strips provide a proper auditory and vibratory alert to warm drivers that they depart their lane?

- Yes
- No

Other

16. What is your gender?

- Male
- Female

17. Which of the following best describes your age (in years)?

- 18-25
- 26-35
- 36-50
- 51-65
- over 65

18. What is the highest level of education that you have completed? (Select only one)

- Graduate school or higher
- College degree
- Some college
- High school
- Did not graduate from high school

19. Do you have any additional comments or suggestions regarding rumble strips?

APPENDIX 6- SURVEY RESPONSES FROM STATE DOTS

Q1. What is your contact info?

Name	Title	Agency	Address	Phone	Email
Richard Weeks	Traffic Safety Section Manager	Arizona DOT	1615 W. Jackson St, Phoenix, AZ 85007	602-712-4382	rweeks@azdot.gov
Gevin Mcdaniel	Design Standards Administrator	FDOT	605 Suwannee Street, MS-32, Tallahassee, FL 32399	850-414-4284	gevin.mcdaniel@dot.state.fl.us
Andy Vandel	Traffic Safety Engineer	SDDOT	700 E. Broadway Ave. Pierre, SD 57501	605-773-4421	andy.vandel@state.sd.us
Jeff Jeffers	State Traffic And Safety Engineer	Alaska DOT	3132 Channel Drive Juneau, AK 99811	907-465-8962	jeff.jeffers@alaska.gov
Timothy E. Barnett	State Safety Operations Engineer	Alabama DOT	1110 John Overton Drive, Montgomery, Alabama 36110	334-353-6460	barnettt@dot.state.al.us
Chris Barretts	Manager	New Jersey DOT	1035 Parkway Avenue, Trenton NJ 08611	609-530-2600	chris.barretts@dot.state.nj.us
Shawn Kuntz	Traffic Operations Engineer	North Dakota DOT	608 East Boulevard Ave, Bismarck, ND 58505	701-382-2673	skuntz@nd.gov
Brian Hurst	Transportation Manager 2	Tennessee DOT	505 Deaderick Street, Nashville TN 37243	615-253-2433	brian.hurst@tn.gov
Brian Hovanec	Eit	Mississippi DOT Traffic	2567 N. West St. Building A, MS 39201	601.359.1454	bhovanec@mdot.ms.gov
Matt Warren	Traffic Safety Engineer	Oklahoma DOT	200 NE 21 St, Room 2A7, Oklahoma City, OK 73105	405-521-3946	mwarren@odot.org
Adnan Qazi	Safety Engineer	AHTD	2261, Arkansas State Highway	501-569-2642	Adnan.qazi@ahtd.ar.gov

			and Transportation Department, Little Rock, AR 72203		
Ken Mammen	Chief Planning Engineer	Nevada DOT	1263 south Stewart street, Carson city, NV 89712	775-888-7335	kmammen@dot.state.nv.us
Darren Mcdaniel	Safety Engineer	Texas DOT	125 E 11th St, Austin, TX 78701	512-416-3331	Darren.McDaniel@txdot.gov
Mary Bramble	Pavement Marking & Delineation Engineer	Michigan DOT	425 W Ottawa St, PO Box 30050, Lansing, MI 48909	517-335-2837	bramblem1@michigan.gov
Michelle May	Safety Program Manager	Ohio DOT	1980 W. Broad Street, Columbus, Ohio 43223	614-644-8309	michelle.may@dot.state.oh.us
Michael Holowaty	Manager, Office Of Traffic Safety	Indiana, DOT	100 N. Senate Ave. Rm. N955, Indianapolis, IN 46204	317-232-5337	mholowaty@indot.in.gov
Tracy Lovell	Transportation Engineer	Kentucky Transportation Cabinet	200 Mero Street Frankfort, KY 40622	502-782-5534	tracy.lovell@ky.gov
Joey Riddle	Safety Program Engineer	SCDOT	955 Park St, Columbia, SC 29202	803-737-3582	riddlejd@scdot.org
Patrick Fleming	Standards Development Engineer	Wisconsin DOT	4802 Sheboygan Ave., Madison, WI 53707	608-266-8486	patrick.fleming@dot.wi.gov
Ronald J. Grandmaison	Project Manager	NH Department Of Transportation	7 Hazen Drive, Concord, NH 03302-0483	603-271-6198	RGrandmaison@dot.state.nh.us
Afshin Jian	State Traffic Engineer	NMDOT	1120 Cerrillos Room 216, Santa Fe, NM 87504	505-827-5490	afshin.jian@state.nm.us
Roy Peterson	Traffic And Safety Engineer	Montana DOT	2701 Prospect Ave; Helena, MT 59601	406-444-9252	roypeterson@mt.gov

Ted Mason, P.E.	Geometric Engineer	Idaho Transportation Department	P.O. Box 7129, Boise Idaho 83707	208-334-8500	ted.mason@itd.idaho.gov
Joe Ouellette	State Safety Engineer	Connecticut DOT	2800 Berlin Turnpike Newington CT 06131	860-594-2721	joseph.ouellette@ct.gov
Chris Speese	Manager, Safety Engineering & Risk Management	PennDOT	Keystone Bldg., 400 North Street, Harrisburg, PA 17120	717-705-1437	chspeese@pa.gov
Bonnie Polin	Safety Manager	MassDOT	10 Park Plaza, Boston, MA 02116	857-368-9636	Bonnie.polin@state.ma.us
Duane Brunell	Safety Manager	Maine DOT	16 State House Station, Augusta, ME 04333	207-624-3278	duane.brunell@maine.gov
Mike Kimlinger	Traffic Standards Engineer	Oregon DOT	4040 Fairview Ind Dr SE, OR 97302	503-986-3583	michael.j.kimlinger@odot.state.or.us
Matthew Carlson	State Highway Safety Engineer	WYDOT	5300 Bishop Blvd, Cheyenne, WY 82009	307-777-4195	matt.carlson@wyo.gov

Q2. In your agency, who should be contacted about rumble strips/stripes, if we need more information?

Q3. Does your agency follow the NCHRP guideline of rumble strip design or you have different specifications for your state?

Answer Options	Response Percent	Response Count
Yes, we follow NCHRP Report 641	14.3%	4
Yes, we follow NCHRP Report 641 with some modification.	50.0%	14
No, we do not follow NCHRP Report 641, we have our own guideline.	32.1%	9
No, we do not follow NCHRP Report 641 and, we do not have any guideline.	3.6%	1
Answered question		28
Skipped question		1

Q4. To what types of roadways rumble strips are applied? (Select all that apply)

Answer Options	Urban Freeway	Rural Freeway	Multilane Highways	Urban Two-lane Highways	Rural Two-lane Highways	Response Count
Shoulder Rumble Strips	20	28	23	7	23	28
Centerline Rumble Strips	1	2	6	6	21	22
Shoulder Rumble Stripes	3	7	12	5	17	17
Answered question						29
Skipped question						0

Q5. What condition/s that may prevent installing rumble strips/stripes? (Select all that apply)

Answer Options	Response Percent	Response Count
Area Type (i.e. urban vs. rural)	96.6%	28
Guardrail	27.6%	8
Pavement Type	41.4%	12
Asphalt Layer Thickness and Condition	89.7%	26
High Bicycle Traffic	41.4%	12
Motorcyclists	6.9%	2
Noise	55.2%	16
Nearby Residents	82.8%	24
Answered question		29
Skipped question		0

Comments:

1. Shoulder width.
2. Practices vary among districts.
3. Our current policy does not allow for centerline rumble strip in passing zones.
4. Speed Limit.
5. In rare occasions rumble strips are omitted due to the needs of residents, such as Amish communities where horse-drawn buggies regularly travel on the shoulder.
6. In addition to the above, we avoid the use of rumble stripes in areas of Amish buggy travel
7. Shoulder widths.
8. Overall current specifications are to accommodate bicyclist whether usage is high or not.
9. Pavement age.

Q6. Have you evaluated the performance of rumble strips in your state?

Answer Options	Response Percent	Response Count
Yes	44.8%	13
No	34.5%	10
We are evaluating now.	20.7%	6
Answered question		29
Skipped question		0

Comments:

1. Currently have a research project underway on the effects of pavement widening and the use of rumble stripes and strips.
2. We are just reaching 3 years after installing Centerline rumbles and will be evaluating the effects.
3. "50 percent crash reduction factor for shoulder rumble strips, 35 percent crash reduction factor for centerline rumble strips."
4. Phase 1 of a research project evaluating the effect/performance of non-freeway rumble strips has already been completed, and Phase 2 will be completed later this year.
5. Purdue University study found both centerline and shoulder rumble stripes to be useful crash reduction strategy on rural two lane highways.
6. We have not evaluated their effectiveness in the last 10-years.
7. First CLRS strip project was finished last week.
8. We retained University of Massachusetts to evaluate our centerline rumble strips but results were inconclusive (mostly due to maintenance issues where some were resurfaced).
9. Not formally, we have attempted to review the performance.

Q7. Have you conducted any benefit cost analysis on rumble strips?

Answer Options	Response Percent	Response Count
Yes	32.1%	9
No	50.0%	14
The analysis is under processing	17.9%	5
Answered question		28
Skipped question		1

Comments:

1. Also use the FHWA guidance of rumbles as a low cost safety improvement. Shoulder rumble stripes are standard item and we do not analyze those for B/C and are installing both shoulder and centerline rumble stripes as systemic type projects.
2. Phase 2 of the research project mentioned above is performing a cost-benefit analysis that will be completed later this year.
3. Not at this time.
4. General cost of implementation is usually not the driving factor whether we put in rumble strips.
5. Use in-state costs and national CMF clearing house factors.

Q8. Does your agency use shoulder rumble strips in combination with centerline rumble strips?

Answer Options	Response Percent	Response Count
Yes	57.1%	16
No	42.9%	12
answered question		28
skipped question		1

Q9. How do you maintain rumble strips? Please, specify in the box below.

Answer Options	Response Count
	21
Answered question	21
Skipped question	8

Comments:

1. We plan to refurbish the pavement marking on rumble stripes the same as other pavement markings.
2. Spring sweeping.
3. Swept as needed.
4. Replaced on the paving cycles.
5. Fog coat, apply new paint as needed.
6. Through resurfacing projects.
7. Some districts may fog seal rumble strips at irregular intervals.
8. Need more info.
9. Reinstall with paving projects or stand-alone rumble stripe projects.
10. Replace as needed.
11. We do not do much if any maintenance on rumble strips, although we do have the rumble strips re-ground when a double chip seal is placed on a roadway.
12. Pavement preservation or resurfacing projects with existing centerline rumble will include re-milling of the rumble.
13. They are re-installed upon resurfacing.
14. No additional maintenance required at this time.
15. I have to talk to maintenance people.
16. Rumbles are reinstalled following overlays as well as some chip seals.
17. We've had good luck fog coating the rumble strips after they've been put in. Beyond that, no continuing maintenance.
18. Currently treated the same as the rest of the pavement.
19. "Currently restripe same as other striping treatments. No other special maintenance. Re-install RS at next pavement treatment."

20. Replace in kind when paving or repair.
21. Seal them with Emulsified Asphalt.

Q10. How frequently you seal rumble strips/stripes?

Answer Options	Response Percent	Response Count
Never	80.8%	21
1-year	3.8%	1
2-year	0.0%	0
3-year	15.4%	4
Answered question		26
Skipped question		3

Q11. Do you receive any complaints about shoulder rumble strips from bicyclists?

Answer Options	Response Percent	Response Count
Yes	82.8%	24
No	17.2%	5
Answered question		29
Skipped question		0

Comments:

1. Not yet. New implementation.
2. Few complaints due to installation policy which accounts for bicyclists.
3. We have modified our typical drawings to reflect changes that help reduce bicyclists concerns.
4. Typically the category of roadway where they are most used negates the presence of bicyclists by law.
5. We have recently changed to 30 feet rumbles with 10 feet spacing. we try to use narrower rumbles with shallower depths.
6. "Bicyclist does not like them. We are currently looking at the 6 inch wide rumble with a 12 foot gap every 48 feet (Colorado uses this pattern) for areas with heavy bike traffic."
7. No, the standard drawing includes periodic breaks in the shoulder rumble stripe to accommodate bicycles.
8. Not often, but there have been some complaints.
9. We started installing mostly centerline rumbles (500 miles) on 2-lane rural, asphalt roadways in 2012. We continued installing centerline in 2013 (~200 miles) 2-lane rural, only on asphalt roadways. The 2014 season is where we begin installing 5 feet asphalt paved shoulders with centerline and shoulder rumbles. We continue to install concrete and asphalt shoulder rumbles on all rural divided highways/interstates. Some urban interstates have rumbles depending on location.
10. We seal rumbles at the time of installation with no other resealing.
11. Shoulder RS only on limited access highways.

12. Shoulder RS an overall concern from bicycle community.
13. Especially when they get installed incorrectly or on narrow shoulders in bike routes. We are moving to address these in new guidance.

Q12. Have you made any provisions to accommodate bicyclists?

Answer Options	Response Percent	Response Count
Yes	86.2%	25
No	13.8%	4
Answered question		29
Skipped question		0

Comments:

1. Provide a break in the rumble strip(e)s for entry and exit to shoulder area.
2. See comment #11.
3. "See previous comment. If we do not have 4 feet of usable shoulder we do not install rumbles unless we have a high number of run off road crashes."
4. "On roadways with high bicycle activity, consideration is given before installation. Things to consider include size of rumble strips, rumble strip material and location of rumble strips on the shoulder."
5. Shoulder rumble strips on non-freeway routes have periodic gaps to accommodate bicyclists moving in and out of the shoulders. The non-freeway pattern consists of a cycle of 48 feet of corrugations followed by 12 feet of gap.
6. The depth of the shoulder rumble stripe is only 3/8 inch and we use a gap pattern.
7. In 2014 WisDOT will install 5 feet paved shoulders on all 2-lane asphalt reconstruction, pavement replacement and new construction projects having equal or greater 6 feet total shoulder width leaving 4 feet clear paved shoulder for wide OSOW, bicycles, and to improve safety for all users.
8. Most shoulder installation has been limited to areas with 6+ feet of shoulder.
9. Skips in pattern, no rumble strip placement where shoulder is < 4 feet, shallower rumble strip pattern we call "bicycle tolerable" rumble strips.
10. We use skips/breaks and in some cases moved them a distance from edgeline
11. Bike gaps and shoulder clearance.

Q13. Have you considered using alternative rumble strips design to accommodate bicyclists?

Answer Options	Response Percent	Response Count
Yes	79.3%	23
No	20.7%	6
Answered question		29
Skipped question		0

Comments:

1. Shoulder stripes in narrower shoulder areas.

2. See #11.
3. Cyclic gaps in non-freeway locations.
4. Yes, 6 inches rumbles with a 12 feet. gap every 48 feet.
5. As mentioned above, our non-freeway shoulder rumble strips now have a cyclical pattern with gaps to allow bicyclists to move in and out of the shoulders without riding over the rumble strips.
6. We have what we believe to be a workable compromise.
7. WisDOT uses a 48 feet rumble and 12 feet gap on 2-lane rural asphalt roadway shoulders with continuous at centerline. Divided roadways have a continuous shoulder rumble concrete and asphalt.
8. MDT considers reducing the lateral width, depth and distance from the travel lane on a case by case basis.
9. Wider stripe. Going to a lesser depth rumble stripe.
10. We provide gaps in rumble to provide intermittent smooth access.
11. We use skips/breaks and in some cases moved them a distance from edgeline.

Q14. Do you have any considerations for motorcyclists when placing centerline rumble strips?

Answer Options	Response Percent	Response Count
Yes	18.5%	5
No	81.5%	22
Answered question		27
Skipped question		2

Comments:

1. We evaluated safety information regarding rumbles and motorcyclists and found little evidence of safety concerns.
2. We have only a few miles of centerline rumble strip, no complaints from motorcyclist that I am aware of.
3. We refer to NCHRP 641 stating that "Based upon recent study, conclusive evidence exists to show that centerline rumbles add no measurable risk to motorcyclists."
4. We've limited most of our centerline rumble strips to no-passing zones.
5. We provide gaps in rumble to provide intermittent smooth access in passing zones.
6. NA - we don't use regularly centerline rumble strips.

Q15. Have you considered using alternative rumble strips design to accommodate motorcyclists?

Answer Options	Response Percent	Response Count
Yes	14.8%	4
No	85.2%	23
Answered question		27
Skipped question		2

Q16. Do you use advanced signs to warn bicyclists and motorcyclists about rumble strips/stripes?

Answer Options	Response Percent	Response Count
Yes	13.8%	4
No	86.2%	25
Answered question		29
Skipped question		0

Comments:

1. We Advance warning signs are placed when construction activities cause traffic to shift over rumble strips.
2. Sometimes.
3. To date we have not placed signage, but will consider if a need is determined.
4. While some areas have chosen to use an advanced warning sign, it is not a requirement.
5. WisDOT did install warning signs along 2-lane rural asphalt roadways when centerline rumble installation began in 2012. However, in 2014 warning signs are no longer installed and previously installed signs will eventually be removed. Initial warning sign installation may be desirable but not for years and years.
6. Not any longer.

Q17. Have you received any complaints about the noise of rumble strips from nearby residents?

Answer Options	Response Percent	Response Count
Yes	82.8%	24
No	17.2%	5
Answered question		29
Skipped question		0

Comments:

1. Only use in rural areas.
2. When used in urban multilane environment, also some complaints by rural residents near to rumble installations.
3. Very few.
4. On one state route the residents complained about the noise and Maintenance staff filled them in.
5. We fairly regularly receive complaints from residents along our rural two-lane, two-way roads complaining about the noise generated by vehicles hitting the shoulder and/or centerline rumble strips. Typically this occurs most in locations that are recently resurfaced and rumble strips are installed where they had never been previously, and complaints taper off after some time.
6. Minimal numbers of complaints. INDOT uses posted speed of 55 mi/h or higher as placement criteria, resulting in use only on rural road segments.

7. Very few, but there have been some noise concerns.
8. WisDOT emphasizes that the rumbles are to help guide all users to stay on the roadway in snow, rain, fog, or other inclement weather. We don't emphasize distracted driver issues, but that is helpful as well. We have noticed that residents affected by noise don't like to "pay that price" for distracted/inattentive drivers.
9. This is particularly true on inside of curves where truck off tracking occurs.
10. Very seldom. Look to have local outreach/info sharing at new RS locations prior to installation. RS brochure has been developed.
11. We attempt to accommodate and have removed in some cases.

Q18. Have you considered using alternative rumble strips design to reduce noise?

Answer Options	Response Percent	Response Count
Yes	55.2%	16
No	44.8%	13
Answered question		29
Skipped question		0

Comments:

1. We do not place rumble strips within 500 feet of receptors.
2. "Same comment for the bicyclist issues. Smaller rumble with gaps."
3. Decrease the depth of the rumble strips.
4. Shallower rumble strips were considered to lessen the noise, however it also resulted in a reduction of the audible and vibratory cues to a driver that they are leaving their lane. Additionally it was found that the noise from a passenger vehicle driving on the rumble strips was actually a lower decibel than a semi-truck just driving by in the lane.
5. We may conduct future studies.
6. Tried sinusoidal and that treatment showed quick pavement failures.
7. We do not put them in near sensitive areas and land uses.
8. We use 3/8 inches depth on rural two lanes.

Q19. Have you received any crash report for bicyclists/ motorcyclists associated with the rumble strips/stripes?

Answer Options	Response Percent	Response Count
Yes	7.4%	2
No	92.6%	25
Answered question		27
Skipped question		2

Q20. Do you take any special measures to increase the night time visibility of rumble stripes?

Answer Options	Response Percent	Response Count
Yes	19.2%	5
No	80.8%	21
Answered question		26
Skipped question		3

Comments:

1. Use double drop thermoplastic.
2. Only the one-time project to install rumble stripes on a narrower segment.
3. 0.60 mil thermo.
4. All rumble stripes have pavement markings placed in the rumble.
5. Not in a general sense. WisDOT has installed rumble stripes, however they are normally placed at the edge of the driving lane and often more noise is a result. We have on occasion installed a double white line. One line outside the edge line with rumbles on test sites and it is effective in reducing noise.
6. The rumble stripe creates excellent wet and night visibility.

Q21. Does your state use transverse or in-line rumble stripes?

Answer Options	Response Percent	Response Count
Yes	79.3%	23
No	20.7%	6
Answered question		29
Skipped question		0

APPENDIX 7- SURVEY RESPONSES OF WYOMING DOT ENGINEERS

Q1. Please, provide your contact information.

Q2. Please rank the features in order of significance directly affecting the installation considerations of rumble strips/stripes?

Rank	Features
1	Lane Departure Crash History
2	Shoulder Width
3	Speed
4	Area Type (i.e. urban vs. rural)
5	Traffic Volume (ADT)
6	Roadway Classification
7	Lateral Clearance
8	Guardrail
9	Bicyclists
10	Pavement Condition
11	Asphalt Layer Thickness
12	Pavement Type
13	Motorcyclists
14	Noise

Q3. What should be the minimum clear shoulder width to install rumble strips (shown in picture A) to accommodate all roadway users?

Answer Options	2 ft	3 ft	4 ft	5 ft	6 ft	Do not install	Response Count
Urban Freeway	6	2	15	1	11	9	44
Rural Freeway	6	3	18	1	16	0	44
Multilane Highways	6	3	18	1	16	0	44
Urban Two-lane Highways	5	1	12	0	6	20	44
Rural Two-lane Highways	7	4	18	1	14	0	44
Answered question							44
Skipped question							1

Comments:

1. Inattentive Drivers are on all highways and freeways, not on streets.
2. Median side rumble strips should be considered for rural divided freeways/highways.
3. 8 feet should be the answer. Cyclists should have 6 feet and then a rumble strip.

Q4. What should be the minimum shoulder width to install rumble stripes (shown in picture C) to accommodate all roadway users?

Answer Options	2 ft	3 ft	4 ft	5 ft	6 ft	Do not install	Response Count
Urban Freeway	9	6	7	1	8	12	43
Rural Freeway	10	3	12	2	10	6	43
Multilane Highways	10	5	8	2	12	6	43
Urban Two-lane Highways	9	4	6	1	4	19	43
Rural Two-lane Highways	13	2	11	2	9	6	43
Answered question							43
Skipped question							2

Comments:

1. I think you could install them on any shoulder width
2. Same as above - 8 feet.

Q5. Which type/s of rumble strips/stripes should be used in different types of roadways? (Select all that apply)

Answer Options	Rumble Strips	Rumble Stripes	Response Count
Interstate	39	11	43
Two-lane and Multi-lane Highways	32	26	43
Comment			5
Answered question			43
Skipped question			2

Comments:

1. Stripes vs. strips would depend on the existing shoulder width.
2. Use the A pattern. There needs to be breaks.
3. As appropriate
4. I think we should put stripes on every highway except 2 lane urban, where no rumble strip/stripe is necessary.
5. Painted stripe on rumble strips is good to let bicyclists and motorcycles where there are rumble strips

Q6. Should there be any minimum speed limit requirement to install rumble strips/stripes? (Select all that apply)

Answer Options	Response Percent	Response Count
30 mi/h	2.5%	1
35 mi/h	2.5%	1
40 mi/h	20.0%	8
45 mi/h	37.5%	15
50 mi/h	12.5%	5
55 mi/h	42.5%	17
Answered question		40
Skipped question		5

Q7. What is the recommended minimum thickness of asphalt layer to install rumble strips? (Select all that apply)

Answer Options	Response Percent	Response Count
2 in	15.8%	6
3 in	15.8%	6
4 in	50.0%	19
more than 4 in	21.1%	8
Answered question		38
Skipped question		7

Q8. What is the recommended condition of asphalt layer to install rumble strips? (Select all that apply)

Answer Options	Response Percent	Response Count
Poor	14.3%	6
Fair	31.0%	13
Good	78.6%	33
Excellent	33.3%	14
Comment		5
Answered question		42
Skipped question		3

Comments:
1. Any
2. This should not matter when looking at run off the road crashes
3. Install if needed
4. These are some of the first areas to break up under heavy traffic
5. I think any hard surface highway should have rumble stripes.

Q9. Should traffic volume be considered when placing rumble strips/stripes? If yes, what should be the minimum Average Daily Traffic (ADT vehicle per day)

Answer Options	Response Percent	Response Count
No requirement	58.1%	25
100	4.7%	2
200	7.0%	3
400	11.6%	5
1000	11.6%	5
>1000	7.0%	3
Answered question		43
Skipped question		2

Q10. What should be the minimum lane width to install shoulder rumble strips (shown in picture A above)?

Answer Options	10 ft	11 ft	12 ft	Do not install	Response Count
Urban Freeway	8	4	20	9	41
Rural Freeway	9	6	25	1	41
Multilane Highways	9	8	22	2	41
Urban Two-lane Highways	7	10	9	15	41
Rural Two-lane Highways	11	11	18	1	41
Comment					5
Answered question					41
Skipped question					4

Comments:

1. If needed should decrease lane width in order to install
2. Lane dimensions do not dictate where a driver would drive distracted.
3. No requirement
4. Most State highways are 11 feet
5. No minimum lane width should be set.

Q11. What should be the minimum lane width to install shoulder rumble stripes (shown in picture C above)?

Answer Options	10 ft	11 ft	12 ft	Do not install	Response Count
Urban Freeway	7	6	15	14	42
Rural Freeway	7	6	21	8	42
Multilane Highways	7	8	19	8	42
Urban Two-lane Highways	7	6	10	19	42
Rural Two-lane Highways	9	7	18	8	42
Answered question					42
Skipped question					3

Comments:

1. Lane dimensions do not dictate where a driver would drive distracted.
2. No requirement
3. No minimum lane width requirement

Q12. Please select features or areas where shoulder rumble strips should be discontinued to avoid adverse consequences. (Select all that apply)

Answer Options	Response Percent	Response Count
Entrance and exit ramps	78.6%	33
When turn lanes are provided	66.7%	28
When lateral clearance is less than required	33.3%	14
At intersections, driveway and median crossings	83.3%	35
Near catch basins	31.0%	13
Near residential areas	52.4%	22
Near pavement joints	21.4%	9
Where curb and gutters are installed	88.1%	37
Guardrail is present	45.2%	19
Other (please specify)		2
Answered question		42
Skipped question		3

Comments:

1. Distracted drivers are located on all roadways no matter what the speed limit, roadway width, or type of roadway construction. Rumble strips assist keeping all distracted drivers on the road. Sleeping drivers I would say they are not applicable to; by the time the driver wakes up it is too late. Center line rumble strips should be installed on all of Wyoming's 2 lane highways in hopes of reducing head on collisions.
2. Highways in urban areas.

Q13. On what type of roadways should WYDOT install centerline rumble strips? (Select all that apply)

Answer Options	Sub-urban multilane undivided highways	Sub-urban two lane roads	Rural multilane undivided highways	Rural two lane roads	Response Count
Roadways with high Average Daily Traffic (ADT)	13	13	25	24	32
Roadways with high number of Head-on/Sideswipe Lane Departure Crashes	19	22	29	36	38
Other (please specify)					0
Answered question					39
Skipped question					6

Q14. What should be the minimum lane width to install centerline rumble strips?

Answer Options	11 ft	12 ft	13 ft	14 ft	Do not install	Response Count
Urban Freeway	9	11	2	1	16	39
Rural Freeway	10	14	4	1	10	39
Multilane Highways	11	15	4	0	10	40
Urban Two-lane Highways	9	13	2	0	16	40
Rural Two-lane Highways	13	20	4	0	3	40
Other (please specify)						2
Answered question						40
Skipped question						5

Comments:

1. Lane dimensions do not dictate where a driver would drive distracted.
2. No minimum

Q15. What should be the minimum lane width to install centerline rumble strips in combination with shoulder rumble strips?

Answer Options	11 ft	12 ft	13 ft	14 ft	Do not install	Response Count
Urban Freeway	8	12	2	2	15	39
Rural Freeway	10	14	4	2	9	39
Multilane Highways	10	15	4	1	10	40
Urban Two-lane Highways	8	13	2	0	16	39
Rural Two-lane Highways	12	19	4	1	3	39
Other (please specify)						3
Answered question						40
Skipped question						5

Comments:

1. Need to place rumble strip right on the stripe line. Wider applications such as C below cannot be done unless we plan to widen the roadways.
2. Center and shoulder rumble stripes should be on all 2 lane highways.
3. No minimum

Q16. Which type of centerline rumble strips do you recommend to install in Wyoming to accommodate motorcyclists?

Answer Options	Response Percent	Response Count
A. Centerline rumble strips within pavement markings.	89.7%	35
B. Centerline rumble strips extend into travel lane.	7.7%	3
C. Centerline rumble strips on either side of pavement markings.	2.6%	1
Answered question		39
Skipped question		6

Q17. In your opinion, how motorcyclists can be accommodated in the roadway with centerline rumble stripes? (Select all that apply)

Answer Options	Response Percent	Response Count
Wide the lane width	11.1%	4
Decrease the depth (less than 1/2 in)	63.9%	23
Do not install rumble strips in passing zone	38.9%	14
Increase the spacing	38.9%	14
Other (please specify)		7
Answered question		36
Skipped question		9

Comments:

1. I do not believe we should install centerline strips
2. Don't know.
3. Unsure
4. I ride motor cycle and have no issues with traversing rumble strips.
5. Narrow spacing is better than wide, even spacing better than skip.
6. I don't think we need to accommodate Motorcycles. We're trying to save their lives.
7. If motorcyclists cannot negotiate half inch, then decrease depth.

Rank	Answer Options	Response Count
1	Adjust the minimum shoulder width and/or lateral clearance.	41
2	Adjust the placement of the rumble strips.	41
3	Adjust the dimensions of rumble strips.	41
4	Sweep shoulder when necessary.	41
5	Do not install rumble strips/stripes on roads with significant bicycle traffic.	41
Answered question		41
Skipped question		4

Q18. Please select features or areas where centerline rumble strips should be discontinued to avoid adverse consequences. (Select all that apply)

Answer Options	Response Percent	Response Count
Intersections and driveways.	76.9%	30
Passing zones.	53.8%	21
Structures. (e.g. Bridges)	84.6%	33
Residential areas.	64.1%	25
	Answered question	39
	Skipped question	6

Q19. Please rank, what can be done to accommodate bicyclists on roadways with rumble strips/stripes?

Rank	Answer Options	Response Count
1	Adjust the minimum shoulder width and/or lateral clearance.	41
2	Adjust the placement of the rumble strips.	41
3	Adjust the dimensions of rumble strips.	41
4	Sweep shoulder when necessary.	41
5	Do not install rumble strips/stripes on roads with significant bicycle traffic.	41
Answered question		41
Skipped question		4

Q20. What is the recommended bicycle gap that should be provided to make a safe exit without striking the shoulder rumble strips/stripes? (The present practice of WYDOT is 12 feet gaps in 48 feet cycles)

Answer Options	Response Percent	Response Count
10 ft gaps in 40 ft cycles	19.4%	7
12 ft gaps in 48 ft cycles	58.3%	21
12 ft gaps in 60 ft cycles	22.2%	8
Other (please specify)		2
Answered question		36
Skipped question		9

Comments:

1. We do not see much bicyclist use, and if they are using the highway they are to the right of the rumble strip on the shoulder
2. Motor traffic higher priority than bicycle traffic

Q21. To accommodate bicyclists, what are your recommendations in terms of the dimensions? (Select all that apply)

Answer Options	Response Percent	Response Count
Depth (3/8 in instead of 1/2 in)	64.7%	22
Spacing (12 in instead of 5 in)	29.4%	10
Width (5 in instead of 7 in)	47.1%	16
Narrow length (less than 12-16 in)	35.3%	12
Non-zero offset (12 in from edge) with at least 4 ft lateral clearance	44.1%	15
Other (please specify)		4
Answered question		34
Skipped question		11

Comments:
1. I don't think bicycles should be on roads
2. No change
3. We do not see much bicyclist use, and if they are using the highway they are to the right of the rumble strip on the shoulder
4. 3 to 4 feet lateral clearance

Q22. Noise could be an issue for nearby residents to rumble strips/stripes, What can be done in this regard? (Select all that apply)

Answer Options	Response Percent	Response Count
Place rumble strips 6-12 in away from the travel lane.	25.7%	9
Adjust the dimensions of rumble strips/stripes.	20.0%	7
Adjust the placement of rumble strips/stripes.	25.7%	9
Increase spacing.	11.4%	4
Consider sinusoidal rumble strips/stripes in and close to residential areas.	40.0%	14
Remove all rumble strips within 1 mile from residential areas.	22.9%	8
Do not install rumble strips in such areas.	62.9%	22
Lower the speed limit in those areas.	22.9%	8
Other (please specify)		6
Answered question		35
Skipped question		10

Comments:
1. No mention on how effective the sinusoidal strips are in reducing crashes--so difficult to answer some of the remaining questions.
2. No change
3. No such complaint has ever been received by myself, or dispatch
4. Crash avoidance benefit outweighs any noise complaint
5. adverse noise effects should not be considered
6. it depends on accident history

Q23. Would you recommend installation of rumble strips/stripes close to national parks?

Answer Options	Response Percent	Response Count
Yes	87.5%	35
No	12.5%	5
Answered question		40
Skipped question		5

Q24. Would you recommend installing the sinusoidal shoulder rumble strips nearby residents and close to national parks?

Answer Options	Response Percent	Response Count
Yes	55.0%	22
No	45.0%	18
Answered question		40
Skipped question		5

Q25. If a high bicycle traffic location, would you recommend installing oval shape strips instead of rectangular strips?

Answer Options	Response Percent	Response Count
Yes	52.5%	21
No	47.5%	19
Answered question		40
Skipped question		5

Q26. Should advance signs to warn bicyclists and motorcyclists about rumble strips/stripes be added? How far in advance?

Answer Options	Response Percent	Response Count
300 ft	9.1%	2
500 ft	81.8%	18
1 mile	9.1%	2
Other (please specify)		13
Answered question		22
Skipped question		23

Comments:

1. This would add a great deal more sign clutter....CL rumbles probably more critical to sign for motorcyclists.
2. They should be able to see them without signs
3. No change
4. No
5. 1/4 mile
6. Not needed
7. Riders should always be evaluating the surface condition, therefore signs are not necessary.
8. No warning
9. No
10. No signs
11. No signing should be required.
12. No
13. No signage

Q27. The current practice of WYDOT is not to place Rumble strips/stripes at locations where major surfacing work is anticipated within the next three years. To reduce lane departure crashes in Wyoming, this policy should be updated to:

Answer Options	Response Percent	Response Count
0-year	7.7%	3
1-year	20.5%	8
2-year	10.3%	4
Keep at 3-year	61.5%	24
Answered question		39
Skipped question		6

Comments:

1. Don't know.
2. If they are not working they should be fixed right away. A worn out rumble stripe indicates a lot of usage by the motoring public
3. I do not believe rumble strips prevent crashes, especially for drivers who fall asleep at the wheel. Using simple perception/reaction times these vehicles have already traveled off the roadway. They may only benefit those who are texting while driving or have some other distraction in the vehicle. They also cause bicyclist's to travel farther out into traffic obstructing the normal flow of traffic.
4. From history the STIP floats enough that a project may slip one or two years.
5. Any rumble strip/stripe is better than none. Saving lives is more important than noise/comfort issues. Effectiveness is more important than cost. Safety is more important than convenience.
6. I do not know of any problems for motorcyclists and rumble stripes or strips. It seems that rumble strips and stripes are most effective when installed in areas identified as areas high in distracted or sleepy drivers in rural areas. Can the accident reports determine why the driver was distracted, ie. Cell phone use or texting... or were they on a long stretch of road and they started to drive as if on auto pilot.

APPENDIX 8- SURVEY RESPONSES OF BICYCLISTS

Q1. Are you 18 years old or older? (Yes/No) (If "No" Terminate the survey).

Answer Options	Response Percent	Response Count
Yes	100.0%	53
No	0.0%	0
Answered question		53
Skipped question		0

Q2. Do you ride bicycles, If "yes", please begin to answer survey questions.(If "No" terminate the survey)

Answer Options	Response Percent	Response Count
Yes	100.0%	53
No	0.0%	0
Answered question		53
Skipped question		0

Q3. How long have you been riding bicycles?

Answer Options	Response Percent	Response Count
Less than 1 year	0.0%	0
2-3 years	3.8%	2
4-5 years	1.9%	1
6-10 years	7.5%	4
11-20 years	9.4%	5
Over 20 years	77.4%	41
Answered question		53
Skipped question		0

Q4. What kind of bicycle(s) do you usually ride? (Select all that apply)

Answer Options	Response Percent	Response Count
Mountain bike	75.5%	40
Road bike	94.3%	50
Hybrid	22.6%	12
Touring bike	22.6%	12
Cruiser	22.6%	12
Recumbent	3.8%	2
Dirt bike	0.0%	0
Answered question		53
Skipped question		0

Q5. How frequently do you ride your bike?

Answer Options	Response Percent	Response Count
Every day	57.7%	30
Weekdays only	1.9%	1
Weekends only	0.0%	0
Some weekdays and weekends	38.5%	20
Infrequently	1.9%	1
Answered question		52
Skipped question		1

Q6. Approximately, how many miles do you ride your bike per week?

Answer Options	Response Percent	Response Count
Less than 10 miles	5.8%	3
Between 10 and 50 miles	44.2%	23
Between 50 and 100 miles	32.7%	17
Between 100 and 200 miles	11.5%	6
More than 200 miles	5.8%	3
Answered question		52
Skipped question		1

Q7. Where do you ride mostly? (Select all that apply)

Answer Options	Response Percent	Response Count
State highways	75.5%	40
Country or county roads	81.1%	43
Bike paths or trails	71.7%	38
City streets	90.6%	48
Sidewalks	3.8%	2
Dirt Roads	32.1%	17
Others	11.3%	6
Answered question		53
Skipped question		0

Q8. Do you consider the presence of shoulder rumble strips when selecting a route?

Answer Options	Response Percent	Response Count
Yes	42.0%	21
No	58.0%	29
Answered question		50
Skipped question		3

Q9. Have you ever run over (come in contact) with a shoulder rumble strips?

Answer Options	Response Percent	Response Count
Yes	96.0%	48
No	4.0%	2
Answered question		50
Skipped question		3

Q10. What was your reaction, the first time you have driven over shoulder rumble strips?

Answer Options	Response Count
Comments	46
Answered question	46
Skipped question	7

Comments:

1. This is loud. Got my attention.
2. Didn't like it.
3. Ride straighter
4. Can't remember
5. This will wake you up
6. My first reaction was annoyance. These strips were designed for concrete trucks and generally are much deeper than necessary. They cause excess tire wear on cars & are dangerous for bicyclists. They can serve their purpose by being intermittent and placed on the inside edge of the lane, NOT on the shoulder or in the MIDDLE of the shoulder as you find on I-80 through Laramie.
7. As a motorist it is useful. As a bicyclist, it is jarring, destabilizing, saps your momentum, and can lead to an accident. If a vehicle is present, it exacerbates the situation.
8. If you just reduce your weight on the saddle they are no problem.
9. Exercise caution!
10. When I was a kid I thought they were great fun, but now they're a lot less fun. I just deall with it because I don't have much option.
11. I rumbled! It's not like I didn't see it but the continuous ones require you to cross them in order to pass other cyclists. I prefer the Intermittent.
12. Little to no reaction
13. Terror. Felt like I could lose control of the bike
14. Ouch...they vibrate the bike and it hurts.
15. Vibration of the bike and rider.
16. Too long ago to remember -- never lost control due to rumble strip but they are jarring.
17. Wasn't desirable but okay
18. Will wake you up
19. That was unpleasant!
20. They took me by surprise initially.
21. Was really scared
22. That's way bumpier than I expected... You could probably knock a wheel out of true!
23. Discomfort, irritation
24. FEAR
25. OMG! I think I just lost a couple fillings.
26. It's quite alerting
27. Not Fun...
28. No problem. They make cycling safer!
29. Get me off of here!
30. On a bicycle, I remember being surprised at how much they jarred me.
31. Shock and discomfort, as it caused a strain in my wrist from the bump of the strip.
32. Good for cars, not great for bikes
33. Rough, affects handling
34. The vibration is very disturbing and can easily throw you off balance if you aren't braced for it. Rumble strips with occasional breaks are much better so you have and way to get 'in and out' without crossing the strips.

35. Hard to control bike
36. "Oh!"
37. I was grateful it was an intermittent shoulder rumble strip so that I was required to ride over it when I was turning left.
38. Shocked me as I wasn't prepared for the vibrations.
39. Surprise
40. It was terrible to control the bicycle.
41. Instability
42. Didn't care for it but now have an appreciation for them. Prefer the intermittent strips.
43. I can't remember
44. This is terrible!
45. Fear!
46. That I should stay inside (on the shoulder) the rumble strip.

Q11. Do you feel uncomfortable riding on roadways with shoulder rumble strips?

Answer Options	Response Percent	Response Count
Yes	38.8%	19
No	61.2%	30
Answered question		49
Skipped question		4

Q12. As a bicyclist, have you ever had any accidents because of shoulder rumble strips?

Answer Options	Response Percent	Response Count
Yes	4.1%	2
No	95.9%	47
If yes, (please specify)		5
Answered question		49
Skipped question		4

Comments:

1. I was just on the Bicycle Tour of Colorado and they did.
2. We had a rider on the Tour de Wyoming go down because of the strips.
3. Came very close before
4. They prevent accidents!
5. Close calls, felt I could loose control when riding skinny wheels

Q13. In your opinion, in the presence of shoulder rumble strips what is the minimum clear shoulder width that should be provided for safe bicycling?

Answer Options	Response Percent	Response Count
3 ft	27.1%	13
4 ft	33.3%	16
5 ft	18.8%	9
6 ft	20.8%	10
More than 6 ft	0.0%	0
Answered question		48
Skipped question		5

Q14. In your opinion, what is the recommended bicycle gap that should be provided to make a safe exit without striking the shoulder rumble strips? (The present practice of WYDOT is 12 feet gaps in 48 feet cycles)

Answer Options	Response Percent	Response Count
10 ft gaps in 40 ft cycles (Figure A)	15.2%	7
12 ft gaps in 48 ft cycles (Figure B)	54.3%	25
12 ft gaps in 60 ft cycles (Figure C)	30.4%	14
Other (please specify)		5
Answered question		46
Skipped question		7

Comments:

1. No opinion
2. 20 feet gaps in 20 feet cycles
3. However, on descents, they need to be more often as we pass slower cyclist more frequently
4. Longer gap 14 - 16', shorter rumble strip 40' or less
5. 12 foot gaps in 40 foot cycles, and gaps across road from T intersections

Q15. Should bicyclists be warned about the presence of shoulder rumble strips?

Answer Options	Response Percent	Response Count
Yes	42.9%	21
No	57.1%	28
Answered question		49
Skipped question		4

Q16. Please rank, what can be done to accommodate bicyclists on roadways with shoulder rumble strips?

Rank	Answer Options	Response Count
1	Increase clear shoulder width	49
2	Place shoulder rumble strips closer to the traffic lane.	49
3	Sweep shoulders more frequently	49
4	Use narrower shoulder rumble strips	49
5	Do not install shoulder rumble strips on roads with significant bicycle traffic	49
Answered question		49
Skipped question		4

Q17. As a driver, do you believe shoulder rumble strips enhance public driving safety?

Answer Options	Response Percent	Response Count
Yes	95.9%	47
No	4.1%	2
Answered question		49
Skipped question		4

Q18. As a bicyclist, will you accept an increase in shoulder rumble strips implementation in the state of Wyoming knowing that they are effective in saving lives?

Answer Options	Response Percent	Response Count
Yes	93.9%	46
No	6.1%	3
Answered question		49
Skipped question		4

Q19. What is your gender?

Answer Options	Response Percent	Response Count
Male	53.2%	25
Female	46.8%	22
Answered question		47
Skipped question		6

Q20. Which of the following best describes your age (in years)?

Answer Options	Response Percent	Response Count
18-25	4.3%	2
26-35	25.5%	12
36-50	19.1%	9
51-65	46.8%	22
over 65	4.3%	2
Answered question		47
Skipped question		6

Q21. What is the highest level of education that you have completed?

Answer Options	Response Percent	Response Count
Graduate school or higher	64.6%	31
College degree	25.0%	12
Some college	8.3%	4
High school	2.1%	1
Did not graduate from high school	0.0%	0
Answered question		48
Skipped question		5

Q22. In which town/city do you live?

Answer Options	Response Count
Answered question	48
Skipped question	5

Q23. Do you have any additional comments or suggestions regarding rumble strips?

Answer Options	Response Count
Answered question	24
Skipped question	29

Comments:

1. More, share the road, signs. Get the word out that cyclist have rights to the roads as well. I pay more in taxes than those people that try and run me off the roads.
2. No
3. I have cycled 211,000 in the last 55 years and have encountered many ugly rumble strips.
4. They need to be shallower, less frequent, shorter strips, and not obstructing the shoulder itself. They should be used only when there is at least a 5-feet wide clean and CLEAN shoulder.
5. Implementation of additional rumble strips is OK, even/especially on high bicycle use roads. The key, though, is that the rumble strips not compromise the available clear space available to bicyclists. If installed, they should be rumble stripes or additional shoulder width should be implemented concurrently.
6. I really like them. Even as a vehicle driver I appreciate them.
7. I appreciate the importance of rumble strips. However, I often have no choice but to ride over them (there are a few areas in Cheyenne where they have been placed on city streets). I ride College Drive frequently, and I find that the shoulders are never swept in some areas (e.g. where there are gravel driveways), and going over the stones really hurts and is dangerous. I really do appreciate having a clear and well-maintained surface I can ride while avoiding the rumble strips.
8. I feel safer riding with them, but the debris from not sweeping is very dangerous, both from flatting and from having it sprayed on us by passing traffic. I also think the driving test needs to have questions on the rights of cyclist, the space allowed them by law, and the consequences of hitting a cyclist. Motorcyclists have gotten awareness, but cyclist remains highly subject to stupidity...like hitting us will teach us a lesson. I wish our bikes were licensed so that we also paid taxes, and were more accepted among the community. I too, drive a pickup truck, but I pass a cyclist like they own their lane. As a cyclist, too many people forget about their mirrors or just don't care. They need to see the pictures of a "hit" cyclist in drivers and know the law, and the consequences. I weigh only a little over 100 pounds and my bike weighs 14 pounds. It doesn't take much to blow me over, especially with RVs and low clearance vehicles, as they generate far more side wind than does a semi!!! Thanks for caring to survey us.

9. I understand the need from a car safety point of view. Wider shoulders, placing the strips closer to traffic and keeping the shoulder free of debris so cyclists can use the shoulder can work. That requires more maintenance dollars from WDOT but worth it.
10. None
11. Keep using rumble strips for safety. They are a minor inconvenience for bikers.
12. As long as the shoulder is wide enough once rumble strips are installed, it is my opinion as a cyclist that they ENHANCE safety for cyclist as they decrease the chance of an inattentive driver from drifting onto the shoulder and striking cyclists.
13. As a cyclist I feel rumble strips make me safer since I get an audible warning if a vehicle is approaching from behind and near the edge.
14. The key is that rumbles should not be on shoulders when there is not sufficient clear space. The old rumbles (still present between Pinedale and Hoback Junction) without gaps and on a shoulder less than 4' wide are a hazard to cyclists. They are the reason we fought them in the first place. To know what it is like, go ride those rumbles and you'll experience the worst of the worst in rumble strip application. There is no place to ride except in the travel lane. On routes that have lots of cyclists and have insufficient shoulder width, rumbles should not be applied. The key is that we cyclists will ride the roads regardless of rumbles or not. Because some motorists are anti-bike won't make us go away. Making roads safer for the sharing of the road is the key.
15. If the shoulder is large, and there are gaps in the strips (honestly most competent cyclists can safely cross a rumble strip quickly and easily at high speed), and the shoulders are kept clean, I think bicycle safety is actually increased by the presence of a rumble strip - it helps keep cars from straying into the shoulder and hitting cyclists
16. I believe that rumble strips placed as close as possible to the traffic lanes are important for both driver, and rider safety. I like seeing them if there is sufficient clear shoulder space.
17. I truly believe that if there is enough room to allow the bike rider (or multiple riders in single file) to be on the outside of the strip safety is increased for both the bike and the driver on the road. With the strip between the bike and the lane of traffic more riders will stay out of the lane and it will alert the driver if they cross into the shoulder. However if it's too narrow to ride between the strip and the edge of pavement more riders will be in the road. Thusly only put it there if there is room on the outside of the strip to the pavement

edge

18. Rumble strips make cycling safer!
19. As long is there is enough room outside of the rumble strip that is clear, cyclists and rumble strips can coexist.
20. Signage warning about them is important so cyclists aren't surprised.
21. Wider shoulders or physical spacing would help increase cycling safety.
22. I found many of the questions to be flawed. For example, I would accept more rumble strips PROVIDING accommodations were made to make it safer for bicyclists. Like wider shoulders, narrower rumble strips, and placing the rumble strip closer to the traffic lane. On the survey, you forced people to answer either Yes or No to this question without the opportunity to qualify the answer. As a bicyclist I am not opposed to rumble strips provided they consider both the driver and the bicyclist safety. I have ridden on too many sections of highway where the rumble strip takes up the entire shoulder or is placed in the middle of the shoulder, forcing the bicyclist to ride in the lane of traffic. This is not safe for driver or bicyclist!
23. Put the rumbles on the fog line, the paint will last longer, and it will give the bikes more shoulder room. Gap the rumbles on the opposite side of the road at T intersections so cyclists can make a left turn and not hit rumbles when entering the bike side of the lane.
24. I think that the current rumble strip configurations along highways 130 and 230 out of Laramie are adequate for accommodating road cyclists.

APPENDIX 9- SURVEY RESPONSES OF NEARBY RESIDENTS

Q1. Are you 18 years old or older? (Yes/No)

Answer Options	Response Percent	Response Count
Yes	100.0%	48
No	0.0%	0
Answered question		48
Skipped question		0

Q2. Which type of rumble strips is installed close to your residence?

Answer Options	Response Percent	Response Count
A. Continuous Shoulder Rumble Strips:	19.1%	9
B. Intermittent Shoulder Rumble Strips:	80.9%	38
Answered question		47
Skipped question		1

Q3. How far is your residence from rumble strips?

Answer Options	Response Percent	Response Count
Within 100 ft	43.8%	21
100-300 ft	43.8%	21
300-500 ft	0.0%	0
500-1000 ft	6.3%	3
More than 1 mile	6.3%	3
Answered question		48
Skipped question		0

Q4. Can you hear the noise from your residence when a driver crosses over the nearby rumble strips?

Answer Options	Response Percent	Response Count
Yes	68.8%	33
No	31.3%	15

Answered question	48
Skipped question	0

Q5. How often can you hear the noise? (select only one)

Answer Options	Response Percent	Response Count
Less than once a day	19.4%	7
1-5 times a day	25.0%	9
5-10 times a day	13.9%	5
More than 10 times daily	41.7%	15
Answered question		36
Skipped question		12

Q6. What time(s) of the day do you hear the noise most? (You may select multiple answers)

Answer Options	Response Percent	Response Count
All the day	12.5%	4
Early morning	28.1%	9
Morning	21.9%	7
Afternoon	18.8%	6
Evening	34.4%	11
Late night	43.8%	14
Midnight	34.4%	11
Other (please specify)		5
Answered question		32
Skipped question		16

Q7. What is the level of noise you hear in your residence when a vehicle runs over rumble strips? (select only one)

Answer Options	Response Percent	Response Count
High	19.4%	7
Moderate	50.0%	18
Low	30.6%	11
Other		4
Answered question		36
Skipped question		12

Q8. External noise produced from rumble strips _____? (Select only one)

Answer Options	Response Percent	Response Count
Acceptable	84.2%	32
Not acceptable	13.2%	5
No opinion	2.6%	1
Answered question		38
Skipped question		10

Q9. What is your preference about installing rumble strips close to residential areas? (Select only one)

Answer Options	Response Percent	Response Count
Do not use	0.0%	0
Limit the use	2.1%	1
Use quieter design	29.8%	14
Remove the existing	0.0%	0
Install rumble strips. but. lower the speed limit	2.1%	1
Use them to save drivers' lives	34.0%	16
No preference	31.9%	15
Answered question		47
Skipped question		1

Q10. Will you tolerate the noise from rumble strips knowing that it saves lives?

Answer Options	Response Percent	Response Count
Yes	97.9%	47
No	2.1%	1
Answered question		48
Skipped question		0

Q11. How long have you been driving? (Select only one)

Answer Options	Response Percent	Response Count
Do not drive	4.2%	2
Less than 1 year	0.0%	0
1-5 year	6.3%	3
5-10 year	20.8%	10
10-15 year	22.9%	11
More than 15 year	45.8%	22
Answered question		48
Skipped question		0

Q12. Have you ever run over (come in contact) with a shoulder rumble strips?

Answer Options	Response Percent	Response Count
Yes	95.8%	46
No	4.2%	2
Answered question		48
Skipped question		0

Q13. What was your reaction the first time you driven over rumble strips? (Please, write in the comment box)

Comments:

1. Surprised
2. Surprised
3. I was wondering what was going on
4. Nervous
5. Ok
6. Annoyed
7. Surprised
8. Surprised
9. Nothing particular
10. Wakes you up
11. Got my attention
12. Freaked out
13. Nothing particular

14. Surprised
15. Nothing particular
16. Surprised
17. Surprised
18. It wakes you up
19. Nothing particular
20. Scared
21. Helpful
22. Nothing particular
23. It wakes you up
24. Scared
25. Shook me
26. Scared
27. Nothing particular
28. Nothing particular
29. It shakes you, makes you nervous.
30. It gets your attention
31. It awakes you, alarms the driver
32. It wakes you up, helps drivers
33. It wakes you up
34. It wakes you up
35. Nothing
36. Get off from it
37. More aware
38. Surprised, no problem
39. What is that noise? Thought it was the car
40. Surprise
41. Startled me
42. Annoying but make me more alert
43. Jerk wheel to get back in lane, did not cross center lane

Q14. Do you believe rumble strips enhance public driving safety?

Answer Options	Response Percent	Response Count
Yes	93.6%	44
No	6.4%	3
Answered question		47
Skipped question		1

Q15. Do you think rumble strips provide a proper auditory and vibratory alert to warm drivers that they depart their lane?

Answer Options	Response Percent	Response Count
Yes	95.7%	45
No	4.3%	2
Other		1
Answered question		47
Skipped question		1

Q16. What is your gender?

Answer Options	Response Percent	Response Count
Male	42.6%	20
Female	57.4%	27
Answered question		47
Skipped question		1

Q17. Which of the following best describes your age (in years)?

Answer Options	Response Percent	Response Count
18-25	25.0%	12
26-35	31.3%	15
36-50	12.5%	6
51-65	16.7%	8
Over 65	14.6%	7
Answered question		48
Skipped question		0

Q18. What is the highest level of education that you have completed? (Select only one)

Answer Options	Response Percent	Response Count
Graduate school or higher	22.9%	11
College degree	33.3%	16
Some college	16.7%	8

High school	27.1%	13
Did not graduate from high school	0.0%	0
Answered question		48
Skipped question		0

Q19. Do you have any additional comments or suggestions regarding rumble strips?

Answer Options	Response Count
	7
Answered question	7
Skipped question	41

Comments:

1. Worth it
2. Create sound barrier
3. Keep the rumble strips
4. Makes the road safer
5. Make them 2nd roadways
6. No
7. No experience in residential areas; only on interstates and highways