

Iowa DOT Synthesis of Transverse Rumble Strips at Rural Stop-Controlled Intersections

tech transfer summary

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RESEARCH PROJECT TITLE

Iowa DOT Synthesis of Transverse Rumble Strips at Rural Stop Controlled Intersections

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This study found that identifying rural intersections for transverse rumble strip installation through a combination of both a systemic, risk-based, and a traditional, hot spot, approach will likely lead to the largest safety benefits by identifying the sites that are at highest risk for future crashes to occur as well as those that have a crash history.

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In response to the proposed House File (HF) 2004 – Rumble Strips, Highway Intersections (commonly known as Baylee’s Bill) in the Iowa Legislature, the Iowa DOT was charged through House Study Bill (HSB) 711, which was succeeded by HF 2644, with studying “the effectiveness of rumble strips in preventing vehicle crashes at certain stop-controlled intersections as determined by the department.”

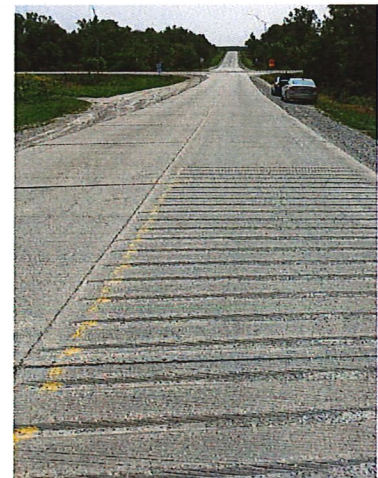
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- Summarize the effectiveness of transverse rumble strips (TRS) at stop-controlled rural intersections based on the relevant current literature
- Document the practices of other state departments of transportation (DOTs) related to the application of TRS at stop-controlled intersections
- Provide cost estimates and benefit-cost ratios for various scenarios of TRS implementation in Iowa

Background

Drivers failing to recognize and stop at rural stop-controlled intersections are a significant safety issue that resulted in an estimated 2–3% of all fatal crashes within Iowa for the five years from 2016 through 2020. One treatment that agencies utilize to help reduce these crashes are TRS.

TRS are a low-cost countermeasure that can be grooved into the pavement or raised strips of materials such as plastic, rubber, or thermoplastic that are placed either across the whole travel lane or the wheel paths to provide an audible and tactile warning to drivers when the strips are driven over.



Nicole Oneyear, InTrans

Transverse rumble strips grooved into the pavement preceding a two-way stop at a four-legged rural intersection near Eddyville, Iowa

Study Description

- A summary of the relevant literature was compiled and analyzed related to the use of TRS at stop-controlled rural intersections.
- A synthesis of state DOT policies was compiled through a search of published policy and responses to a survey that was sent to state DOT safety engineers through the American Association of State Highway and Transportation Officials (AASHTO) Safety Committee listserv.
- An economic analysis was conducted to determine the estimated benefit-cost ratios of implementing TRS in Iowa using two different site selection installation criteria.

To put the economic analysis in context, Baylee's Bill proposed a systematic installation of TRS at virtually all high-speed, rural paved, stop-controlled approaches that intersect with primary roads throughout Iowa. The research team used the last five years of Iowa crash data (for 2016 through 2020) along with a crash modification factor (CMF) and the Iowa DOT Intersection Database to determine the number of intersections that would be treated under the suggested systematic approach versus using a targeted approach for installing TRS based on the top 5% of high-crash intersections (from the 1,845 intersections of interest in the Iowa DOT Crash Database).

Key Findings

Summary of Literature

Research has found reductions in crashes ranging from about 20% to 40% at stop-controlled intersections after the installation of TRS (Srinivasan et al. 2012 and Torbic et al. 2015). TRS have also been found to reduce driver speeds in the approach to the intersection in the range of 1 mph to 5 mph (Harder et al. 2006, Ray et al. 2008, Thompson et al. 2006, Yang et al. 2016).

Common concerns related to TRS include noise and adverse impacts on motorcyclists and bicyclists. Unlike other longitudinal rumbles, which are only struck when a driver is leaving their lane, the placement of TRS results in them being struck theoretically by every driver, which makes the noise produced a greater concern. This is often combated by not placing TRS near residential areas or only placing them a set distance from residences.

Research has shown using a shallower depth rumble has resulted in lower external noise while still producing adequate internal noise to be effective. However, an optimal depth/noise ratio has not been well established.



Hossein Naraghi, InTrans

States with wheel path designs (like this one in Minnesota) include Minnesota, New Mexico, and Texas

To better accommodate cyclists, wheel path designs or paved shoulders are sometimes used. A few states utilize a standard design that uses a wheel path only TRS design that allows for the accommodation of bicyclists and motorcyclists who can avoid traversing the rumbles by traveling in the space between them.

Additional concerns that are often voiced have been so far to be unfounded. For instance, research has found no increase in erratic maneuvers nor issues related to maintenance.

Synthesis of State DOT TRS Usage

Eight states, including Iowa, were found to have published policies that could easily be accessed. Of the 25 DOTs that responded to the survey, only two states that responded did not allow for TRS in advance of rural stop-controlled intersections.

Iowa's current policy allows for the use of TRS on roads with speed limits of 55 mph+ and where noise is not a concern. It also allows for the use on roads with speed limits under 55 mph if warranted by an engineering study.

States that allowed for TRS appeared to mainly take a targeted approach to selecting sites for installation with all but two noting that less than 25% of their rural county paved intersections in their state currently had TRS installed. Two states (North Dakota and South Dakota) responded that they take a more systematic approach, while the rest mostly took a traditional hot-spot approach.

Four states noted that they specifically require a history of crashes before installing TRS, while an additional nine noted they often use crash history. A systemic-like approach based on risk level was taken by states such as Maryland, Missouri, Ohio, and Wisconsin, which included selecting sites with risk factors that increased the likelihood of a ran-stop-sign crash occurring. Some of these risk factors included sites with inadequate stopping sight distance or intersections that followed a long approach.

Six states required other less intrusive countermeasures be tried before TRS were installed. Common countermeasures that were considered included removing sight obstructions, doubled-up stop signs and advance warning signs, oversized signs, flags or flashing beacons on advance warning or stop signs, on pavement signing, light-emitting diode (LED) stop signs, intersection lighting, and overhead flashing beacons.

Cost Analysis Summary

The research team used their economic analysis results to develop benefit-cost ratios for a systematic approach versus a targeted approach to determine if significant differences exist in the economic benefits between the two approaches.

Estimated benefit-cost ratios for TRS implementation

Intersection Road Type	Method	Benefit-Cost Ratio
Primary Road	Treat All Intersections	13.177
	Treat Top 5% of Intersections	66.722
Secondary Road	Treat All Intersections	3.695
	Treat Top 5% of Intersections	22.948

Primary=Iowa DOT maintained; Secondary=county maintained; Top 5%=top 5% of high-crash intersections based on all crashes used in the analysis for Iowa from 2016 through 2020

Implementation Readiness and Benefits

The cost analysis found that, while both the systematic approach and the targeted approach were economically sound investments with benefit-cost ratios over 3 for all scenarios, the ratios were five to six times greater for the targeted approach.

It should be noted that the CMF utilized for this analysis was most appropriate for locations with a demonstrated failure-to-yield crash history. Therefore, the benefits of the estimated benefit-cost ratios may be overestimated or underestimated for any particular intersection in Iowa.

National guidance suggests TRS should be used sparingly in order to remain effective due to their effectiveness being dependent on them being out of the ordinary (Newman et al. 2003). Therefore, a targeted approach choosing sites both systemically and through hot spot analysis will likely lead to the largest safety benefits by identifying the sites that have a crash history as well as those that are at highest risk for future crashes to occur.

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Iowa DOT Synthesis of Transverse Rumble Strips at Rural Stop-Controlled Intersections

**Final Report
December 2021**

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Center for Transportation
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Hossein Naraghi, left, and Nicole Oneyear, right, InTrans

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IOWA DOT SYNTHESIS OF TRANSVERSE RUMBLE STRIPS AT RURAL STOP- CONTROLLED INTERSECTIONS

**Final Report
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- Greg Karssen

EXECUTIVE SUMMARY

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1. INTRODUCTION

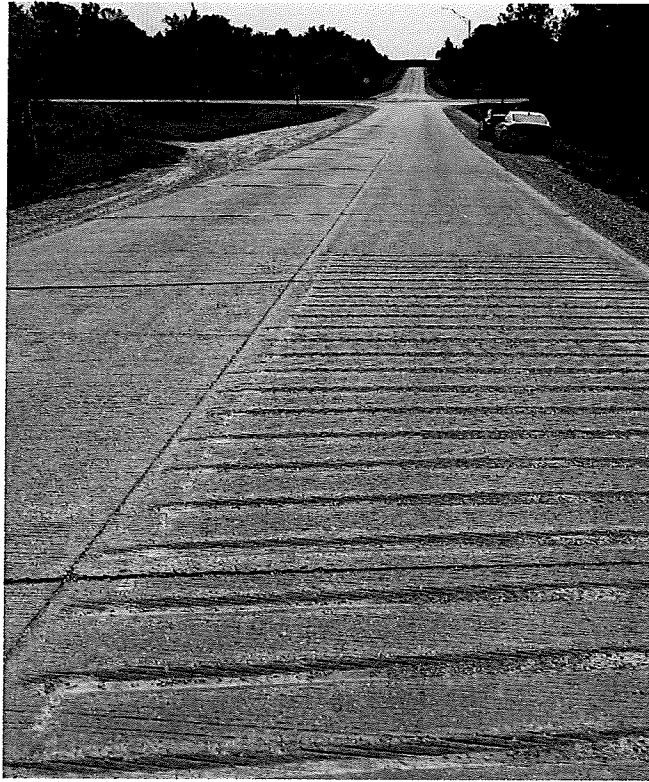
From 2016 through 2020, rural intersections in Iowa accounted for 12% of crashes in rural areas. They also accounted for 41.7% of all serious injury crashes and 14.3% of all fatal crashes within the state, representing a significant but poorly understood safety problem.

Crashes at rural intersections are particularly problematic when high speeds on intersection approaches are present. Additionally, fatal crash rates are approximately two times higher in rural areas than in urban areas (FHWA 2012a, Zwerling et al. 2005) due to a variety of factors, including higher speeds and longer response time for emergency medical services (EMS).

During the five year period from 2016 through 2020 in Iowa, drivers failing to recognize and stop at rural stop-controlled intersections resulted in an estimated 2–3% of the fatalities within the state, and 5.6% of fatalities during that time were coded with ran stop sign as the major cause of the crashes. However, upon further examination of the crash reports and narratives, it was concluded that at least half of the crashes that were coded as ran stop sign should have been coded as failure to yield.

Characteristics correlated to the failure to stop at stop signs include age (McGwin and Brown 1999, Keay et al. 2009), speed, vision obstruction, and inattention/distraction (Campbell et al. 2004).

One treatment that agencies use to help reduce failure to yield crashes are transverse rumble strips (TRS) (see Figure 1).



Nicole Oneyear, InTrans

Figure 1. Transverse rumble strips preceding a two-way stop at a four-legged rural intersection near Eddyville, Iowa

TRS are a low-cost countermeasure that provide an audible and tactile warning to drivers when they are traversed, and they have the advantage of being effective in low visibility conditions (e.g., rain, fog, darkness). Most TRS are grooved into the pavement, but strips of plastic, rubber, thermoplastic, or other material have been used in some cases, even though most of these alternative applications are temporary.

One of the crashes that TRS may have prevented occurred in Iowa on the evening of November 30, 2019. On this evening, Baylee Hess was traveling north on 21st Avenue in Benton County in inclement weather that included fog, sleet, and hail. Likely as a result of the poor visibility due to the weather conditions, Hess did not stop at the intersection of 21st Avenue and US 30 and collided with a tractor trailer, which resulted in her death.

Due to this crash and other similar crashes at rural high-speed, stop-controlled intersections, House File (HF) 2004 – Rumble Strips, Highway Intersections (commonly known as Baylee’s Bill) was proposed by the Iowa State Legislature in 2020. This bill proposed requiring transverse rumble strips in advance of all stop signs located on highways where the highway enters or crosses a primary highway and the minor approach is a paved rural road with a speed limit of at least 55 mph.

While ultimately not passed in that session, it resulted in the Iowa Legislature charging the Iowa Department of Transportation (DOT) to study the effectiveness of TRS at stop-controlled intersections in Iowa. This was included in the bill under House File 2644 (which was the successor to House Study Bill [HSB] 711) on page 5, Section 3, which contained the following language:

“The department of transportation shall study the effectiveness of rumble strips in preventing vehicle crashes at certain stop-controlled intersections as determined by the department. The department shall submit a report of its findings to the general assembly on or before December 31, 2021.”

This report helps meet the objectives of that charge by including a summary of relevant research related to TRS at rural stop-controlled intersections, a synthesis of practices related to TRS at DOTs across the country, and an analysis of potential benefits and costs associated with different scenarios of implementing TRS at rural stop-controlled intersections in Iowa.

2. LITERATURE REVIEW

National Cooperative Highway Research Program (NCHRP) Report 500 Volume 5: A Guide for Addressing Unsignalized Intersection Collisions lists TRS as a low-cost countermeasure to implement at rural intersections to decrease crashes that occur due to running the stop sign. TRS aren't generally expected to reduce crashes when drivers select inappropriate gaps between vehicles (Neuman et al. 2003). As a result, when TRS are applied at high-crash locations where the primary crash type is due to gap selection, they may be less effective.

TRS are considered appropriate for stop-controlled intersections where drivers have a history of failing to stop at the stop sign. According to NCHRP documents, the effectiveness of TRS is dependent on them being out of the ordinary and, therefore, it is suggested they be used sparingly. To reduce the number of TRS installations, other less intrusive countermeasures such as signing upgrades, supplemental pavement markings, and obstruction clearing are suggested to be tried first; if they are found to be ineffective, then move onto TRS (Harwood 1993 and Neuman et al. 2003).

TRS are meant to draw drivers' attention through the tactile and auditory warnings they provide, but they do not communicate to drivers what action to take. Therefore, in order to be effective, they should be placed so that either the upcoming decision point (i.e., the intersection) or a sign identifying the action that may be required (i.e., advance warning or stop sign), is clearly visible as the driver passes over the rumble strips. They should be placed such that they provide drivers adequate time to understand the action that needs to be taken and then take it (i.e., brake or stop).

The benefits of TRS at rural intersections have been evaluated through a variety of metrics such as crash reductions and crash surrogates. Additional drawbacks to TRS, however, have also been identified, including noise pollution, difficulty for motorcyclists and bicyclists in traversing, difficulties for snowplow and roadway maintenance, as well as erratic maneuvers by drivers (Harwood 1993). Research available on the benefits and drawbacks are summarized in this chapter.

2.1 Crash Reductions

Various studies have looked at what effect TRS have on crashes and crash rates at stop-controlled intersections and found them to be an effective strategy to improve safety at intersections with a history of drivers failing to stop at stop sign controlled approaches. These studies have ranged from a review of past work (Harwood 1993), to surveys of crash modification factor (CMF) values that DOTs utilize (Agent et al. 1996 and Gan et al. 2005), to two more recent studies that used the more sophisticated empirical Bayes analysis method.

As a result of these two recent studies (Srinivasan et al. 2012 and Torbic et al. 2015) 35 three- or four-star CMFs exist on the CMF Clearinghouse website. In an NCHRP Synthesis, Harwood (1993) summarized 10 before and after crash studies that had been conducted from 1962 to 1991. Harwood noted that the majority of studies look only at crashes, not crash rates, did not utilize

control sites, and that only two of the studies confirmed their results were statistically significant. These two studies included one by Carstens and Woo (1982) that utilized 21 sites in Iowa and found a significant crash rate reduction of 51% when looking at all crashes at intersections on the primary highway system where TRS were installed. It was noted, however, that there may be regression to the mean present, as the decreases in crashes were only seen at intersections with higher than 2.0 crashes per million entering vehicles. The other study was from the UK (Sumner and Shippey 1977) and had 10 sites, not all of which were at stop-controlled intersections. Some of the sites included horizontal curves, were in small towns, and were at entrances to roundabouts.

A 2004 Institute of Transportation Engineers (ITE) Toolbox, which was developed using a variety of sources, listed a 35% reduction in all crashes when TRS are installed prior to stop signs at rural stop-controlled intersections. The same guide also listed a potential 2–44% expected reduction in crashes for installing rumble strips on signalized and/or unsignalized intersection approaches based on a report by Agent et al. (1996), which was a collection of survey information from states on the CMFs that they utilize for certain countermeasures. These reductions are both included in the CMF Clearinghouse as unranked CMFs. For the 2–44% range the single value of 23%, which is the middle point of the range, is what the clearinghouse lists.

In a 2005 study, Gan et al. surveyed state DOTs on the crash reduction factors (CRFs) utilized for various countermeasures. This survey resulted in two CRFs. The first was a 28% reduction in all crashes when rumble strips are installed at stop-controlled approaches in Montana, and the second was based on data from Alaska that showed a 90% reduction in rear-end crashes due to rumble strips on approaches to intersections. No information was provided on how these CRFs were developed.

In two more recent studies, which were both performed using empirical Bayes before-after crash analysis, Srinivasan et al. (2012) and Torbic et al. (2015) found reductions in fatal and injury crashes ranging from a 21.5% reduction in the Srinivasan study to a 37% reduction at three-legged intersections in the Torbic study. The study by Srinivasan, which was conducted using sites in Iowa and Minnesota, also found an increase in property damage only (PDO) crashes of 19.1%; however, the study by Torbic, which was based on data from intersections in Arkansas, Kansas, Missouri, North Dakota, and Oregon, found either no significant change or a decrease in these PDO crashes.

The reasons for the mixed results are potentially due to biasing site selection to locations with right-angle crashes. These right-angle crashes may have been due to improper gap selection and not to drivers failing to recognize the intersection, which are the crashes that TRS target (CH2M Hill, Inc. 2017).

Most of the states in the Torbic study, aside from North Dakota, which took a more systematic approach where they treated all intersections that meet a predetermined criteria regardless of safety issues, utilize a more traditional hot spot approach (i.e., crash history) for TRS installation. Therefore, these studies may not estimate the benefits of TRS that are applied either systemically to only high-risk sites nor systematically to all intersections.

2.2 Impact on Driver Behavior

In addition to the crash studies mentioned above, other studies have been completed that have evaluated the effectiveness of TRS at intersections using crash surrogates related to driver behavior. These surrogates include speed, stopping behavior, and erratic maneuvers. The use of these surrogates assume that a speed reduction as drivers approach the intersection correlates to a reduction in crashes. The surrogates also assume that an increase in the percentage of drivers coming to a full stop results in a reduction for intersection crashes.

Overall, studies have generally found a speed reduction ranging from just under 1 mph to 5 mph for stop-controlled intersections after installation of TRS (Harder et al. 2006, Ray et al. 2008, Thompson et al. 2006, Yang et al. 2016). On the other hand, one study found an increase in speed variation after installing TRS (Zaidel et al. 1986). Increases in drivers making full stops have been found; however, negligible changes have been found in relation to no stops (Harwood 1993), and no increases were seen in erratic movements once TRS were installed (Miles et al. 2006, Yang et al. 2016).

Most of the work that has been completed looking at the effect of TRS on stopping behavior was conducted more than 30 years ago. A summary of these studies was completed as part of Harwood's (1993) synthesis of rumble strips to enhance safety. The studies saw increases of approximately 30% of drivers making full stops and saw about a 4% increase in full stops or partial stops when TRS were present (Kermit and Hein 1962, Owens 1967, Illinois Division of Highways 1970, Carstens and Woo 1982, and Zaidel et al. 1986).

A study by Zaidel et al. (1986) looked at the impact of 1/2 in. to 5/8 in. high raised asphalt TRS on speed, deceleration behavior, and stopping behavior at a rural intersection in Israel. The researchers found that speeds significantly decreased upstream of the rumbles in the year after (~40%); however, they also noticed an increase in speed variation. The researchers noticed no change in stopping behavior but did note that compliance before the TRS was already quite high at 82%.

Another study looking at reductions in speed approaching 10 intersections in Minnesota found that TRS reduced driver speeds 2 mph to 5 mph (Harder et al. 2006). A similar before and after study of nine approaches in Texas found either no statistically significant change in speed or a small 2 mph to 3 mph statistically significant reduction in speeds (Thompson et al. 2006). The researchers noted that, as these reductions were below 4 mph, they were not considered to be successful at producing a meaningful reduction in speeds (Thompson et al. 2006).

As part of NCHRP Project 3-74, Ray et al. (2008) looked at the impact of transverse rumbles on five high-speed intersection approaches in Texas. The researchers utilized the Texas DOT (TxDOT) standard of raised rumbles that are 4 ft long and cover the two vehicle wheel paths with spacing 2 ft apart. The researchers evaluated changes in speeds downstream of the TRS at the perception-reaction point (approximately 250 ft upstream of the intersection) and saw an average reduction of 1.3 mph. Data were also collected at the location of the TRS and 100 ft upstream of the intersection where no significant changes were found.

A study by Yang et al. (2016) looked at the effect of TRS on reducing speed on the approaches of five high-speed intersections, four of which were signalized, in Alabama. The raised thermoplastic TRS that were used were placed anywhere from 680 ft to 1,350 ft upstream of the stop bar. The researchers found that average reductions in speed ranged from just under 1 mph to over 8 mph, which were statistically significant reductions at all signalized intersections but not during the daytime at the one unsignalized intersection included in the study. The researchers had also included cameras and noted that they did not see any erratic behaviors once the TRS were installed.

A study by Miles et al. (2006) used the same pattern as that used in the NCHRP study at two rural intersections in Texas to determine if the placement of the TRS was resulting in drivers making erratic maneuvers. Using more than 15 hours of video, similar to Yang et al. (2016), the researchers found no erratic maneuvers (i.e., sudden braking or swerving). They did note that some drivers did shift their position to avoid the rumbles; however, it was a smooth movement and no drivers entered into the opposite lane.

2.3 Concern with Transverse Rumbles

While effective at reducing failure to yield crashes at stop signs, TRS are an intrusive treatment that create additional noise. This can disturb residents, cause potential issues for motorcyclists and bikers, especially when a full lane width design is used, and lead to additional maintenance issues. The research available on these concerns is summarized in this section.

2.3.1 TRS and Noise

One of the major complaints that are made about TRS is that they result in noise pollution. To get an audible response in the vehicle, noise also results outside the vehicle, and, unlike shoulder edge line and centerline rumbles, due to their placement, TRS are usually struck by every vehicle and not just those at risk of leaving their lane or the roadway. This is why distance to homes is often a consideration when determining if TRS should be placed.

Some states choose to not place rumbles in residential areas. Others, as the Federal Highway Administration (FHWA) notes, have a minimum required distance to nearby residences. These specified distances range from 100 ft to 2,000 ft (FHWA 2015a). The distance is most commonly about 650 ft, which another study noted was approximately the distance at which rumble strip noise is tolerable (Bahar et al. 2001).

Research has found that the noise produced by rumble strips varies based on the designs of the individual rumble strips. Miles and Finley (2007) studied how the dimensions (length, width, depth, and spacing) of rumble strips affect the noise produced. The researchers were only able to look at milled-in edge line, lane line, and centerline rumble strips but did find that, as width increased to a certain point, the noise produced increased. They also found that length and spacing had an effect on the noise produced. They did not look at rumble strips of different

depths, but previous research has found that, as depth increases, noise increases (Khan and Bacchus 1995, Bucko and Khorashadi 2001).

A more recent study was conducted to evaluate a method for adapting previously installed TRS to reduce noise levels. Hurwitz et al. (2019) tested epoxy-filled transverse rumble strips (EFTRS), which took traditional milled-in rumble strips and added an epoxy, reducing the depth of the rumble strip to less than 1/4 in., to see if it would reduce exterior noise. Using a probe vehicle, the researchers found that the exterior noise generated by the EFTRS was noticeably less than the traditional rumble strips by an average of 3.49 dBA, but it was still four times that of ambient road noise. However, their test did not measure whether there were any changes to the audible or tactile warning within the vehicle.

In terms of practice, the research results confirmed that an epoxy retrofit applied to TRS can effectively reduce roadside noise. Therefore, filling TRS with epoxy can provide an intermediary treatment between full-depth TRS and repaving the road. However, the impact of shallower rumble strips may provide less tactile vibration for drivers and therefore be less effective. The TRS can still be used to improve highway safety (alerting drivers of traffic control device changes), while reducing roadside noise for nearby residences

A study based in Korea was published looking further at the impact of transverse rumble strip design impact on noise. The researchers studied four different designs and measured noise both outside and inside the vehicle, as well as vibration inside three test vehicles that traveled over the TRS at multiple speeds (An et al. 2017).

- Type A: 10 cm (4 in.) wide x 1 cm (0.39 in.) deep x 20 cm (8 in.) spacing between strips
- Type B: 5 cm (2 in.) wide x 1 cm (0.39 in.) deep x 15 cm (6 in.) spacing between strips
- Type C: 10 cm (4 in.) radius x 1 cm (0.39 in.) deep x 20 cm (8 in.) spacing between strips
- Type D: 0.9 cm (0.35 in.) wide x 0.6 cm (0.25 in.) deep x 3.8 cm (1.5 in.) spacing between strips

The researchers found a design that features 1 cm (0.39 in.) deep, with a 10 cm (4 in.) radius and 20 cm (8 in.) distance between strips (Type C) performed the best in terms of reduced exterior noise while providing the greatest tactile warning within the test vehicles.

Further research is needed to see how the results of research like that by An et al. (2017) translate to the United States and the vehicle types driven here, as well as testing how changing the length of the rumble, such as placing it in just the wheel paths, may also affect the noise produced.

Two ongoing research projects for the Illinois DOT (IDOT) through the Illinois Center for Transportation are studying TRS designs that produce less external noise while still providing the necessary internal noise and vibration to be effective (Chehab 2021).

2.3.2 Motorcyclist and Bicyclist Road Use

Traversing TRS for motorcyclists and bicyclists can be uncomfortable and could lead to these road users losing control. Therefore, roadways with high bicycle traffic or designated bike routes may want to strongly weigh the benefits of installing TRS before implementing them. Much of the guidance on accommodating cyclists in relation to rumbles is related specifically to shoulder, edge line, and centerline rumbles.

The *Manual on Uniform Traffic Control Devices for Streets and Highways* (MUTCD) includes guidance on rumble strips in temporary traffic control situations under Chapter 6: Temporary Traffic Control Devices (FHWA 2012b). Under Section 6F.87, the MUTCD provides guidance related to TRS. It notes that TRS should not be placed on bike routes, and TRS should only be placed on roadways that are used by cyclists if a clear path of 4 ft is provided at each edge of the roadway or on each paved shoulder.

A few states utilize a standard design that uses a wheel-path only TRS design. This allows for the accommodation of bicyclists and motorcyclists who can avoid traversing the rumbles by traveling in the space between them. States with wheel path designs include Minnesota, New Mexico, and Texas (see Figure 2).



Hossein Naraghi, InTrans

Figure 2. Wheel path transverse rumble strips in Minnesota

Additionally, Arizona and New Jersey take into account if 4 ft of paved shoulder is present; if not, the TRS width ends 4 ft from the edge of the pavement in Arizona and 4 ft from the edge line in New Jersey. Maryland's width depends on whether bikes are present or not on the road. If bikes are present, they require a minimum clear path of 4 ft to be provided at each edge of the roadway or each paved shoulder as per guidance in the MUTCD.

2.3.3 Maintenance

One common concern related to the installation of rumble strips is that they may result in the pavement degrading faster or will increase maintenance needs. For instance, the ITE *Unsignalized Intersection Improvement Guide*, when discussing TRS, notes that when applied to approaches with high volumes of truck traffic, they can result in significant maintenance activities (ITE 2015). However, the FHWA highlights in their *Rumble Strip Implementation Guide* that milled rumble strips require little to no preventive maintenance (FHWA 2015b).

When raised rumble strips are used, and specifically raised markers or thermoplastic strips, maintenance may be required as they may be knocked loose (FHWA 2015b). While not specifically mentioning TRS but other longitude rumbles, which should not have drastically different maintenance needs than TRS, the FHWA on their Rumble Strips and Rumble Stripes Pavement and Maintenance webpage notes the following:

“Maintenance crews were initially concerned that heavy traffic would cause shoulder pavements with rumble strips to crumble faster, or that the freeze-thaw cycle of water collecting in the grooves would crack the pavement. These worries have proved to be unfounded where rumble strips were installed in pavements in fair to good condition. Rumble strips have little if any effect on the rate of deterioration of new pavements.” (FHWA 2016)

The FHWA also notes the following related to snow:

“Weather appears to play no significant role in the durability of milled rumble strips. Field observations refute concerns about the effects of the freeze-thaw cycle as water collects in the grooves. These observations show that wind and the action of wheels passing over the rumble strips in fact knock debris, ice, and water out of the grooves.” (FHWA 2016)

Most of the research that has been done related to the maintenance impacts of rumble strips has been focused on the much more widely implemented edge line, shoulder, and centerline rumble strips. While TRS have some unique features, the research should be mostly transferable to TRS.

A proof of concept study by Coffey and Park (2016) found no statistically significant difference between the performance of the pavement for shoulders that had rumble strips and those that did not. The Texas Transportation Institute (TTI), under NCHRP Project 14-46, is currently conducting a study to further explore this topic of maintenance needs and the effect that rumble strips have on pavement deterioration. This study is focusing on centerline, edge line, and shoulder rumble strips.

Another concern related to TRS is the impact of maintaining the TRS during maintenance operations such as chip sealing. A study by Tufuor et al. (2017) looked at the impact that maintenance efforts have on the effectiveness of rumble strips. The study collected in-vehicle noise and vibration readings for five different rumble strip depths ranging from 1/8 in. to 5/8 in. to study the implications of chip sealing on rumble strip effectiveness.

When chip sealing is performed, if the rumbles are not re-milled, the depth of the rumble strip will be reduced and therefore may become less effective. The 1/8 in. difference in depth between each rumble strip depth used was to simulate the depth reduction due to chip seal. The study found that this 1/8 in. reduction in depth resulted in no practical difference in noise and vibration, and, therefore, the researchers did not suggest re-milling rumbles after chip sealing maintenance efforts.

3. STATE DOT TRS USAGE

Through a current and ongoing project, Transverse Rumble Strips at Rural Intersections, which is also being conducted by the Institute for Transportation—for the Minnesota DOT (MnDOT)—the team researched the TRS designs that DOTs utilize in advance of stop-controlled intersections. Through this work, the team found that about 22 states had easily accessible plans for TRS at stop-controlled intersections. They also found that no two states utilize the same exact pattern for TRS.

The list of states for which plans were easily available was compiled and utilized to begin searching their websites for published policies. The team found that seven states had policies that were easily accessible. After the Iowa DOT policy and guidance, which is next, these seven state policies are summarized, followed by the results of a state survey that the team conducted.

3.1 Iowa DOT Policy and Guidance

The Iowa DOT's current policy (at <https://iowadot.gov/traffic/manuals/pdf/18a-01.pdf>) related to TRS at stop-controlled rural intersections and their usage falls under the *Iowa DOT Traffic and Safety Manual* Section 18A-1 and was last updated in 2014. It notes that TRS are generally used on rural intersection approaches that are 55 mph or greater and not near homes or businesses. The policy lists other countermeasures that can be used if TRS are not placed. It does not note any crash history requirements nor specific distances from homes or business that TRS must be placed. The exact wording is as follows:

“Rumble strips are generally used in rural areas in advance of locations where primary highway traffic must stop at a Stop sign. A rumble strip panel consists of a series of grooves in the surface to provide a tactile and audible awareness for the driver that may not be fully aware of the other devices in advance of the Stop sign. They are not generally used where the speed limit is less than 55 miles per hour or where the sound would be obtrusive to nearby residences or businesses. When it is decided not to use rumble strips where the speed limit is 55 miles per hour or more, alternative measures may be taken, such as installation of beacons, placement of flags on existing signs, installation of signs on both sides of the road, or use of larger signs. Rumble strips may be installed at locations where the speed limit is less than 55 miles per hour if indicated by a traffic engineering study for that location. The State Traffic Engineer will provide assistance at the request of the District Office.”

The rest of the guidance in the document, as well as in the *Iowa DOT Design Manual* Section 6A-7 and the *Iowa DOT Standard Road Plan PV-10*, notes the locations that the two panels of rumble strips must be placed in advance of the intersection along with the design of the individual rumbles.

3.2 Other State's Published Policies

3.2.1 Illinois

The Illinois policy is located in the *Bureau of Local Roads and Streets Manual – Chapter 31 Cross Section Elements* in Section 31-1.09: Rumble Strips. This document was from August 2016. The policy states the following:

“Transverse rumble strips may be considered on approaches to intersections and horizontal curves to indicate a need for the driver to slow down or stop. The use of transverse rumble strips supplements the visual warnings (signs and signals) with audible and sensory indications and has some obvious and attractive advantages. Such warnings may reach a fatigued or dozing driver who might miss the visual ones. With the sound created from transverse rumble strips, placement near residences or quiet zones (schools, hospitals, etc.) should be reviewed prior to placement.

“Transverse rumble strips should be located in advance of some sign (Stop Ahead, Stop, etc.) that either warns of or describes the action required on the part of the motorist. This will assist the driver to better understand the purpose of the transverse rumble strips.” (IDOT 2016)

3.2.2 Maryland

Maryland's policy is located in their *Guidelines for Application of Rumble Strips and Rumble Stripes*, which was revised in 2014. The policy for TRS at approaches to intersections includes signalized, stop-controlled, and roundabouts. The policy states the following:

“Transverse rumble strips should be considered on the approaches to intersections where there is a demonstrated safety problem (e.g., high crash rate), adequate trial of other warning devices has failed to reduce the crash frequency, and any of the following conditions exist:

- Inadequate stopping sight distance or signal/sign visibility
- Intersection is at an unexpected location
- Intersection is located on a roadway on which motorists have not been required to stop for a long period of time or distance” (MDOT SHA 2021)

3.2.3 Missouri

Missouri's policy is located in Section 626.4: Transverse Rumble Strips in their Engineering Policy Guide (EPG) online. The EPF page was last updated in November 2020. The policy is for all applications of TRS, not just in advance of stop signs. The policy states the following:

“Transverse rumble strips are placed in the driving lane as a warning device alerting drivers about the need to take action. Transverse rumble strips, having a definite role as a traffic control

device to enhance safety, should be considered as enhancements to warning signs such as the Stop Ahead (W3-1) or the various Curve (W1 series) signs.

“Placement of transverse rumble strips in the traveled way should be considered when one or more of the following exist and other conventional methods (advance signing, increased sign size, flashers on stop signs, etc.) have been tried.

- When the intersection or roadway condition is hidden from view by either a horizontal or vertical curve, based upon stopping sight distance
- When the intersection or roadway condition has a history of crashes caused by failure to observe a traffic control device
- When the traffic control device follows a long tangent

“Rumble strips placed in the traveled way should not be overused. If rumble strips are used at too many locations, they may lose their ability to gain the motorist’s attention. For this reason, transverse rumble strips should only be used at locations where conventional methods are not working.” (MoDOT 2020)

3.2.4 North Dakota

North Dakota’s policy is located within their 2020 *Standard Specifications for Road and Bridge Construction* (NDDOT 2020). Under Section 760: Rumble Strips, it notes the following for intersection rumble strips: “Saw cut intersection rumble strips at all STOP conditions of state highways.” It also notes, in Table 760-01, exclusion areas that include posted speeds 45 mph or less, urban areas, or areas with curb and gutter.

3.2.5 Ohio

Ohio’s policy is located in their *Traffic Engineering Manual* Section 1415-2: Transverse Rumble Strips, which was revised as of January 2021. Their policy states the following:

“Transverse rumble strips should be considered for use in advance of intersections where there is a documented problem involving angle and/or rear-end crashes related to red light or STOP sign violations only after all other countermeasures have been tried and proven ineffective.

“Possible locations include isolated high-speed or expressway signalized intersections and intersections with inadequate stopping sight distance.

“If used, rumble strips should be installed on the approach(es) with the crash problem. They are usually installed on a stop approach at a STOP sign-controlled intersection, but may also be installed on the mainline, or on a signalized approach when the crash problem is related to that particular approach.

“For highways with a speed limit less than 50 mph, the last rumble strip should be at least 200 ft from the Stop Line, or, if none, from the point where the road user should stop. If the speed limit is 50 mph or greater, the last rumble strip should be at least 300 ft from the stopping point.” (Ohio DOT 2021)

3.2.6 Oregon

Oregon’s policy is located in the January 2022 *Traffic Line Manual* under Section 245: Transverse Rumble Strips. Their policy states the following:

“Permanent milled-in transverse rumble strips may be installed on an approach to a ‘STOP’ sign (R1-1) where crash history indicates a significant number of intersection crashes would be treatable with transverse rumble strips and where more conventional treatments have proved ineffective.” (Oregon DOT 2022)

Under their required approvals, they note the following:

“An engineering study and region traffic engineer approval is required for installation of transverse rumble strips associated with ‘Stop Ahead’ (W3-1) warning signs on state highways or local public road approaches to a state highway.

“An engineering study and state traffic-roadway engineer approval is required for all other installation of transverse rumble strips on state highways.

“Engineering studies on transverse rumble strips must document a safety problem correctable with the use of transverse rumble strips and consider noise impacts if located near residences or campgrounds.” (Oregon DOT 2022)

They also include the following under Design Issues:

“Contact the Construction Section’s Pavement Services Unit to determine if the pavement surface is in sufficiently good condition to install transverse rumble strips.

“Other conventional treatments typically include oversize signs, signs on both sides of the roadway, higher intensity sign sheeting, STOP AHEAD pavement markings (see Section 125), and increasing the stop bar width (see Section 150).

“Transverse rumble strips installed on local public road approaches to state highways typically need an intergovernmental agreement (IGA) between ODOT and the local road authority detailing who will pay for installation and maintenance of traffic control devices approaching the state highway, including the transverse rumble strips.

“Potential adverse effects of transverse rumble strips include noise generated by vehicles continuously traversing them, effects on plowing operations, maintenance concerns with durability, and concerns by motorcyclists and bicyclists. There is a possibility that drivers might go around them by driving in the opposing lane, though there is some evidence this is not common for short rumble strip sets (Miles et al. 2006).” (Oregon DOT 2022)

3.2.7 Wisconsin

Wisconsin’s policy is located in the August 2020 *Facilities Development Manual* Chapter 11 Section 15 under subsection 1.8.1 – Rumble Strips Policy and Design Criteria. It includes a note specifically about the impacts related to noise, which states the following:

“WisDOT has carefully considered noise generation in the development of our rumble strips policy. The design and horizontal locations/offsets of the rumbles should minimize noise generation. WisDOT feels that the safety benefits of rumbles, described in FDM 11-15-1.8, outweigh the impacts of the noise generated a majority of the time. Therefore, it is appropriate to take a systemic approach to the implementation of rumbles. However, the regions may be aware of a few unique situations where noise generation may factor into decisions to either not install rumbles, or to provide gaps in the rumble strip installations. Unique situations may be where current high speed (50 mph posted) facilities may have posted speeds reduced in the near future because of more traffic or congestion, or future land uses allow for more adjacent developments where noise may be an issue. There may be existing isolated developments/communities or single dwellings where there is high likelihood for noise concerns; then consider providing gaps in the rumbles (no rumbles) for approximately 500 ft on each side of the potential problem sites. Policy expectations are that decisions to either not install or to gap the rumbles will be kept to a minimum. Design Justifications for these decisions are to be documented in the DSR.” (WisDOT 2020)

The policy for TRS states the following:

“Travel lane rumbles are typically used near intersections (not on shoulders). Travel lane rumbles must be used in combination with other traffic control such as advance-warning signs and typically under stop-controlled conditions. There are a couple scenarios where travel lane rumbles may be installed:

- At the intersections of two highways that have similar functional classes or AADT volumes may be similar. This could be at the intersections of two STHs or the intersections of STHs and CTHs having similar traffic volumes, or at least the driver expectancies are that the facility they are driving on would not have a stop control condition.
- There are perceived or demonstrated crash problems when drivers are unaware that they are supposed to stop for crossing traffic or where the geometrics of the roadways may prevent the drivers from seeing the approaching intersections such as at vertical crest curves or horizontal curves.

“Noise generation is a primary concern with these types of rumble installations for people at residential or other properties close to the installations. It is important to communicate with and coordinate with affected property owners prior to installations. It is important to not over use these treatments as to become common place so that drivers are desensitized to the noises and vibrations generated by the rumbles. See SDD 13A8 and SDD 13A9 for more detailed information on the rumble installations and rumble locations prior to intersections.” (WisDOT 2020)

3.3 Survey and Results

In addition to accessing the seven state policies, the team also sent a survey to state DOT safety engineers to gather additional information on state policies. The team developed a survey that was able to be completed in 10 minutes or less using the Qualtrics online survey platform.

The survey consisted of 9 to 15 questions, depending on the respondent’s answers, for participants that allowed TRS at stop-controlled intersections in their state, and 6 to 9 questions, depending on their answers, for those that did not. It included questions related to their policies and practices related to TRS implementation as well as a question on the amount of their intersections involving rural paved county roads that have TRS to understand their usage. Additionally, respondents were questioned as to whether their state has ever filled in TRS and what led to that occurring.

A copy of the survey is included in the appendix. The fill-in-the-blank questions within the survey only appeared if the answer to the previous question was yes.

The survey was distributed September 28, 2021, with the help of Kelly Hardy of the American Association of State Highway and Transportation Officials (AASHTO) to the AASHTO Safety Committee listserv. As of the cutoff date of October 28, 2021, 25 states returned the survey (for a 50% response rate).

Nearly all of the states (23 of the 25) that replied allowed for the use of TRS at stop-controlled intersections. The two states that replied they did not were Rhode Island and Vermont. Noise and the lack of rural locations were the reasons included for not allowing for the use. Additionally, the Massachusetts respondent answered no but then, later in the survey, noted that installation was allowed; it was just that they had not installed any at stop-controlled intersections.

Of the states that did allow for the use of TRS, the responses showed that all but two had less than 25% of county paved roads with TRS in their state. Four states specifically required a history of focus crash types before installing, while an additional nine noted they often used crash history. Only two states noted that they required that TRS, when installed, be placed a certain distance from homes. These policies existed to mitigate noise. Additionally, only six states required other countermeasures be tried before TRS were installed.

Common countermeasures that were considered included removing sight obstructions, doubled up stop signs and advance warning signs, oversized signs, flags or flashing beacons on advance warning or stop signs, on-pavement signing, light-emitting diode (LED) stop signs, intersection lighting, and overhead flashing beacons. Table 1 summarizes the responses, and the following sections summarize the information provided for each state.

Table 1. Summary of survey responses for states that allow TRS

State	Published policy?	Percentage of secondary roads with TRS	Crash history required?	Other countermeasures tried first?	Policy on distance from homes or businesses?	Filled in TRS?
AL	unsure	less than 25%	yes	unsure	no	unsure
AK	no	less than 25%	no	no	no	unsure
AR	no	less than 25%	yes	no	no	unsure
CA	no	less than 25%	other	unsure	no	unsure
GA	no	more than 25% but less than 50%	no	no	no	unsure
HI	no	less than 25%	no	no	no	no
IL	yes	less than 25%	other	no	no	yes
KS	yes	less than 25%	other	no	no	unsure
LA	no	less than 25%	no	no	no	no
MD	yes	less than 25%	other	yes (no specific)	no	unsure
MN	no	less than 25%	other	yes (specific)	no	yes
MO	yes	less than 25%	yes	yes (specific)	unsure	no
MT	unsure	less than 25%	no	No	unsure	unsure
NE	no	less than 25%	no	No	no	unsure
NH	no	less than 25%	other	yes (specific)	yes	yes
ND	yes	more than 25% but less than 50%	no	no	no	yes
OR	yes	less than 25%	other	no	no	yes
SC	unsure	less than 25%	yes	yes (specific)	no	unsure
SD	yes	less than 25%	no	no	yes	unsure
UT	no	less than 25%	other	no	no	unsure
WA	yes	less than 25%	no	no	unsure	unsure
WI	yes	less than 25%	other	yes (specific)	no	yes

Iowa (IA) did not respond to the survey itself and sent their policy to the lead principal investigator for this project, as covered at the beginning of this chapter; Massachusetts (MA) is not included due to the fact that they answered no and therefore did not provide the information for the questions included in the table; Rhode Island (RI) and Vermont (VT) also answered a different set of questions so are not included in this table

3.2.1 Alabama

Alabama allows for the use of TRS in advance of rural stop-controlled intersections. It was unknown if there was a published policy; however, it was noted that a history of failure-to-yield

crashes are required before installing TRS, and there was no requirement on how far from homes they may be installed. Additionally, it was unknown if countermeasures must be tried first. They were unsure if TRS had previously been filled in within the state. At their rural paved county intersections, less than 25% currently had TRS.

3.2.2 Alaska

While TRS are allowed at stop-controlled intersections in Alaska, they do not have a published policy. They also have no requirements related to crash history, first trying other countermeasures, nor a policy related to the distance from homes or businesses TRS can be placed. Like the majority of states that responded, less than 25% of their paved rural county intersections currently had TRS. They were unsure if TRS had previously been filled in.

3.2.3 Arkansas

Arkansas allows for the use of TRS, however, does not have a published policy. While not requiring other countermeasures to be tried first or having a minimum TRS distance from homes, they do require a history of crashes before installing TRS at stop-controlled intersections. Less than 25% of their paved rural county intersections currently had TRS, and it was unknown if they have filled in TRS.

3.2.4 California

California allows for the use of TRS at stop-controlled intersections. They do not have a published policy nor require a crash history; however, installations typically are crash history-driven. They do not have a minimum distance from homes or businesses and were unsure if they require other countermeasures to be tried first. Like the majority of other states, less than 25% of the paved rural county intersections currently had TRS installed. They were unsure if TRS have been previously filled in.

3.2.5 Georgia

Georgia allows for the use of TRS at stop-controlled intersections and do not have any requirements related to crash history, use of the other countermeasures first, or distance from homes. Between 25% and 50% of their paved rural county intersections currently had TRS. It was unknown if they have filled in TRS in the past.

3.2.6 Hawaii

Hawaii does not have a published policy, but they do allow for the use of TRS in advance of stop-controlled intersections. They do not require a crash history nor other countermeasures to be tried. They also do not have a requirement for how far from homes or businesses TRS must be

installed. Less than 25% of the paved rural county intersections currently had TRS present, and TRS have not been previously filled in.

3.2.7 Illinois

Illinois allows for the use of TRS at stop-controlled intersections and is one of the states with a published policy as described in the previous section. From the survey, they also noted they generally require a crash history; however, they will consider an engineering study of an intersection and proven predictive methods. They do not require other countermeasures to be tried first and, while they do not have a required minimum distance from homes, they do try to stay more than 250 ft from them. Less than 25% of their rural paved county intersections currently had TRS. They noted they have previously filled in TRS due to residential complaints.

3.2.8 Kansas

Kansas allows for the use of TRS at stop-controlled intersections and has a published policy on the use of them. They noted they are working on their policy, but the current policy states “Traveled Way (Transverse) Rumble Strips may be recommended when: 1) there are three or more right-angle accidents in a 12-month period involving stop sign or traffic signal violations, and the accident rate is higher than 15.0 accidents per TMEV, and the previous town or last intersection road requiring a stop or vehicle maneuver exceeds 15.5 miles.” As mentioned in the policy, they do require a crash history when suggesting to place TRS. They do not require other countermeasures to be tried first nor have a requirement for distance from homes. Less than 25% of their paved rural county intersections currently had TRS, and it was unknown if they had previously filled in TRS.

3.2.9 Louisiana

Louisiana does not have a published policy on TRS at stop-controlled intersections; however, they do allow for the use of them. There are no requirements related to the placement (i.e., no crash history, other countermeasure, or distance from homes requirements). Less than 25% of their county roads had TRS presently, and they have not filled in any TRS in the past.

3.2.10 Maryland

As covered in the previous section, Maryland has a published policy related to TRS installation at intersections. While not explicitly requiring a history of crashes, it is one of the criteria for when TRS should be considered. It also notes that other warning devices (i.e., countermeasures) should be tried before the TRS are considered. It does not list any specific countermeasures though. It also notes locations with risk factors present (e.g., inadequate stopping sight distance) should be considered. They do not have a minimum distance from homes. Less than 25% of their paved rural county intersections had TRS present. It was unknown if TRS had been previously filled in.

3.2.11 Massachusetts

Massachusetts responded to the survey that TRS are not allowed within the state, but later qualified that, while allowed, they are just not used in advance of rural intersections. They do not have a published policy and have previously filled in TRS; they just were not related to an intersection application.

3.2.12 Minnesota

Minnesota allows for the use of TRS in advanced of stop-controlled intersections but does not have a published policy. They do not have a crash requirement; however, they utilize several criteria to determine when TRS could be applied. They don't require, but suggest, first trying additional countermeasures. These countermeasures include advance signing, post gating stop signs, advance warning pavement markings (on-pavement signing), warning flashing beacons, other pavement markings, LED stop signs, or intersection lighting. They have no minimum distance from homes or businesses. They noted they have previously filled in TRS due to noise complaints. Less than 25% of their paved rural county stop-controlled intersections currently had TRS installed.

3.2.13 Missouri

Missouri allows for and has a published policy related to TRS placement on their roads, as covered in the previous section. They note a crash history or when other risk factors are present. These risk factors include when there is inadequate stopping sight distance or when the intersection follows a long tangent. They also require other conventional countermeasures be tried first and fail to address the safety issue. These countermeasures include advance signing, increased sign size, and flashers on stop signs. No minimum distance from homes or businesses was included within the written policy, and it was unknown if any minimum distance was required. Less than 25% of their paved rural county intersections currently had TRS. Additionally, they have not filled in TRS in the past.

3.2.14 Montana

While allowing for TRS at rural stop-controlled intersections, it was not stated if there was a published policy. They have no requirements related to crash history nor other countermeasures to be first tried. It is unknown if there is a minimum distance from homes or businesses. Less than 25% of their paved rural county intersections currently had TRS. It was also unknown if they had filled in TRS in the past.

3.2.15 Nebraska

Nebraska allows for the use of TRS but does not have a published policy. Less than 25% of the rural paved county intersections in Nebraska currently had TRS. They do not have requirements

related to crash history, first trying other countermeasures, nor minimum distances from homes or businesses. It was unknown if they have ever filled in TRS.

3.2.16 New Hampshire

While allowing for TRS at stop-controlled intersections, New Hampshire does not have a published policy for TRS. They noted that they are sparsely used within the state (fewer than five installations) due to the noise issues that TRS bring about. They do not require a crash history but do require trying other countermeasures before installing TRS. These other countermeasures include red flashing beacons on oversized stop signs, oversized Stop Ahead signs, and overhead flashing intersection beacons that flash red for the stop approaches and yellow on the through, non-stop, roads. They noted they require TRS to be away from homes and businesses, but don't have a set policy on that distance. As mentioned, they have very few installations within the state and therefore less than 25% of their rural paved county intersections currently had TRS. Additionally, they have previously filled in TRS due to vigorous noise complaints from residents.

3.2.17 North Dakota

North Dakota allows for and has a policy for the use of TRS at stop-controlled intersections, as included in the previous section. In addition to the policy, North Dakota installs TRS at T-intersections where a crash problem has been identified or where one currently exists or at the T intersection of two state highways. As a result of this systematic policy, North Dakota currently had between 25% and 50% of its paved rural county intersections with TRS installed. As their policy is more systematic, they do not have requirements for a crash history, to try other countermeasures, or to be a minimum distance from homes. They have previously filled in TRS due to noise complaints from nearby homeowners or businesses. They noted that they try to avoid filling them in and, when or if they do, they try to move them further from the business or residence.

3.2.18 Oregon

Oregon has a published policy that allows for the use of TRS at stop-controlled intersections, as summarized in the previous section. As noted in the policy, they do not explicitly require a crash history but noted an installation likely would not be approved if this wasn't part of an engineering study that is required to be completed for all potential installations. They do not require other countermeasures be tried first; however, their policy does note that installations may occur at sites where conventional countermeasures have been ineffective. They have previously filled in TRS due to noise complaints but do not have a minimum TRS distance from homes and businesses. Like the majority of other states that responded to the survey, less than 25% of their paved rural county intersections currently had TRS.

3.2.19 Rhode Island

TRS are not allowed in advance of rural stop-controlled intersections within Rhode Island due to noise concerns. Additionally, they do not have many rural intersections. At intersections with issues, they have been implementing other countermeasures such as double stop signs, double advance warning signs, larger signs, and pavement markings. They have not previously had a TRS policy; however, they have previously filled in some TRS due to noise complaints.

3.2.20 South Carolina

South Carolina allows for the use of TRS in advance of rural stop-controlled intersections; however, it is unknown if they have a published policy. They do require a crash history at proposed TRS sites and require sites to first double up and increase signage to see if they are able to address the safety problem before installing TRS. They do not have a minimum distance from homes or businesses. Less than 25% of the rural paved county intersections currently had TRS installed. It is unknown if they have ever filled in TRS in the state.

3.2.21 South Dakota

South Dakota allows for the use of TRS in advance of stop-controlled intersections and has a policy that was not found during the team's previous investigation. They noted the policy states that "TRS will be placed on all state highway system approaches to stop-controlled intersections in rural locations." This policy does not require a crash history or first trying other countermeasures. It does note a minimum distance (500 ft) from homes for conventional TRS and suggests consideration of rumble strip designs that reduce noise, such as sinusoidal rumbles, if within 500 ft of homes. While the systematic policy applies to state highways, they noted that less than 25% of intersections on paved rural county roads currently had TRS. It is unknown if TRS have been filled in.

3.2.22 Utah

Utah allows for TRS; however, they do not have a published policy. While they do not have an official policy, they noted that, in practice, they would make sure there is a safety issues (i.e., crash history) at the proposed site. They noted they do not require other countermeasures to be tried first nor a minimum distance from homes. Less than 25% of the rural paved county intersections currently had TRS, and it is unknown if TRS have been filled in.

3.2.23 Vermont

Vermont does not allow the use of TRS in advance of rural stop-controlled intersections. It was noted they were not allowed due to issues with winter maintenance and noise. They have not previously had a TRS policy, nor have they ever filled in TRS in the state.

3.2.24 Washington

Washington allows for the use of TRS in advance of stop-controlled intersections and has a published policy related to their use, which was not discovered through an online search. This policy is located within their Design Manual, and its most recent edition came out in September 2021. The policy states that they are allowed in advance of stop-controlled intersections and directs, when planned, to “Contact the HQ Design Office for additional guidance on the design and placement of transverse rumble strips.” They noted that they do not require a crash history nor other countermeasures to be tried first. It was unknown if TRS are required to be a minimum distance from homes or businesses or if TRS had been previously filled in. It was noted that less than 25% of their paved rural county intersections had TRS.

3.2.25 Wisconsin

Wisconsin allows for the use of TRS in advance of stop-controlled intersections and has a policy that was included in the previous section. While not having a required crash history, their policy states they should be considered where a crash history exists. They noted Wisconsin generally reviews the crash narratives to determine if a crash was a failure to stop (which TRS would help target) versus a failure to yield. This is due to the fact that crashes are often miscoded as failure-to-yield when the narrative indicates it was a failure-to-stop crash. They also require other countermeasures be tried before installing TRS. For blown stop sign crashes, they noted they first try removing sight obstructions, then make signing adjustments (double-marking), followed by installing permanent flags on signs. If those fail, they move on to TRS. Finally, if TRS are not improving safety, they move to electrical countermeasures such as LED stop signs. They do not have a minimum distance from homes; however, the policy noted that noise should be taken into consideration and noted 500 ft from residences as a potential distance. TRS have been filled in, usually during chip sealing on the county-maintained approaches. Wisconsin had less than 25% of their rural paved county intersections with TRS currently installed.

4. ECONOMIC ANALYSIS OF TRS IMPLEMENTATION IN IOWA

Baylee’s Bill proposed systematically installing TRS at high-speed, rural paved, stop-controlled approaches that intersected with primary roads throughout Iowa. The following section describes how the researchers determined the number of intersections that would be treated under the suggested systematic approach. The section after that uses the last five years of crash data, along with a CMF for installing TRS at rural intersections, to develop benefit-cost (B-C) ratios for a systematic approach versus a targeted approach to installing TRS to determine any significant differences in the economic benefits between the two approaches.

4.1 Identification of Intersections without TRS

The Iowa intersection database was developed in the period of 2013 through 2018. In addition to location, a number of intersection variables were included. However, presence of TRS was not included during initial coding. It was decided that presence of TRS was important and presence was coded for the remaining intersections. As a result, part but not all of the intersections in the data noted this feature. Thereby, the team coded TRS for the remaining intersections. This was done using GoogleEarth and Pathweb.

The updated database was then utilized to extract the number of intersections of interest (i.e., paved, speed limit 55 mph or greater, stop-controlled, rural areas, intersection with a primary road) that did not have TRS currently present. This was broken down by primary versus secondary intersecting roads as well as the number of legs. This information is summarized in Table 2.

Table 2. Summary of intersections of interest without transverse rumble strips in Iowa

Intersection Road Type	Number of Legs	Number of Intersections	Estimated Cost
Primary Road	3 legs	195	\$487,500
	4 legs	101	\$505,000
	Total	296	\$992,500
Secondary Road	3 legs	1,060	\$2,650,000
	4 legs	489	\$2,445,000
	Total	1,549	\$5,095,000
Total		1,845	\$6,087,500

Primary=Iowa DOT maintained; Secondary=county maintained

Additionally, a column was added to determine the approximate cost of adding TRS to these intersections, as shown. A cost of \$2,500 was assumed per approach given that amount was provided by the Iowa DOT based on past contracts. As seen from the data in the table, nearly 300 primary intersections and more than 1,500 secondary intersections could be considered for installation of TRS.

Assuming a cost \$2,500 per approach and that both minor legs of a four-legged road would be treated, the total cost to the state would be about \$6,087,500. If the cost of installation could be brought down to \$1,500 per approach, the total cost would fall to \$3,652,500.

4.2 Benefit-Cost of TRS Implementation Scenarios

The team also compared the cost and likely benefits of implementing TRS at intersections in Iowa not already treated with TRS.

Five years of crash data from Iowa (2016–2020) were extracted from the Iowa DOT crash database. From there, all crashes that occurred on the 1,845 intersections of interest were extracted for these five years. These were identified by using Iowa DOT geographic information system (GIS) data to spatially join any crash that occurred within 250 ft of each intersection. This distance was used given it is widely accepted that the area of influence related to an intersection is 250 ft. Crashes were then aggregated by severity type for the primary and secondary roads and are summarized in Table 3.

Table 3. Summary of crashes at the intersections of interest

Intersection Road Type	Severity Level	Total Crashes for All Intersections	Total Crashes for Top 5% of Intersection*
Primary Road	Fatal	16	5
	Major Injury	36	8
	Minor Injury	124	29
	Possible Injury	130	39
	Property Damage Only	580	157
Secondary Road	Fatal	22	7
	Major Injury	68	29
	Minor Injury	189	74
	Possible Injury	168	77
	Property Damage Only	751	254

Primary=Iowa DOT maintained; Secondary=county maintained

*Top 5% of highest crash intersections used in the analysis for Iowa from 2016 through 2020

The combined results showed 1,198 crashes occurred within 250 ft of a secondary road intersection of interest while 886 occurred within 250 ft of a primary road intersection of interest from 2016–2020.

For intersections of interest involving a primary road for the minor leg, 227 (76.6%) of the potential 296 intersections had at least one crash in the last five years. The intersections that had crashes ranged from one crash up to 36 crashes, with an average of almost four crashes. For secondary roads as the minor leg, only 586 (37.8%) of the potential 1,549 intersections had at least one crash in the last five years. The intersections that had crashes ranged from one crash up to 20, with an average of slightly over two.

Once crashes were identified, the approximate top 5% of intersections based on the number of crashes for both primary and secondary roads were extracted. This allowed the team to compare the B-C ratio of a systematic approach (applying TRS to all intersections of interest) versus taking a more targeted approach (applying TRS to the intersections with the most crashes). It should be noted that the top 5% did not specifically look at intersections with the focus crash type associated with TRS (i.e., ran stop sign crashes), which is the approach one would likely take when taking a more targeted approach.

Once the crash values were extracted, a CMF of 0.87 from Torbic et al. (2015) was utilized to determine the expected crash reduction (benefit) due to installing TRS. This CMF is for applications at rural intersections and applies to all crash types and severities and is the suggested value to use by the Iowa DOT Planning Level Crash Reduction Factor (CRF) List. The cost of each crash severity was then multiplied by the expected number of crashes that were predicted to be prevented.

The cost values that were utilized were extracted from the Iowa DOT Traffic and Safety Benefit Cost Spreadsheet. These values included \$4,500,000 for fatal crashes, \$325,000 for major injury crashes, \$65,000 for minor injury crashes, \$35,000 for possible injury crashes, and \$7,400 property damage only crashes. From there, the estimated crash savings over five years were able to be calculated.

The results for a more systematic approach (treating all intersections) can be seen in Table 4, while the values for a more targeted approach (treating top 5% of high-crash intersections) can be seen in Table 5.

Table 4. Expected benefits of treating all intersections with TRS (systematic approach)

Intersection Road Type	Severity Level	Crash Reduction Expected	Cost Per Crash	Cost Savings
Primary Road	Fatal	2.08	\$4,500,000	\$9,360,000
	Major Injury	4.68	\$325,000	\$1,521,000
	Minor Injury	16.12	\$65,000	\$1,047,800
	Possible Injury	16.9	\$35,000	\$591,500
	Property Damage Only	75.4	\$7,400	\$557,960
	Total			
Secondary Road	Fatal	2.86	\$4,500,000	\$12,870,000
	Major Injury	8.84	\$325,000	\$2,873,000
	Minor Injury	24.57	\$65,000	\$1,597,050
	Possible Injury	21.84	\$35,000	\$764,400
	Property Damage Only	97.63	\$7,400	\$722,462
	Total			

Primary=Iowa DOT maintained; Secondary=county maintained

Table 5. Expected benefits of treating top 5% of high-crash intersections (targeted approach)

Intersection Road Type	Severity Level	Crash Reduction Expected	Cost Per Crash	Cost Savings
Primary Road	Fatal	0.65	\$4,500,000	\$2,925,000
	Major Injury	1.04	\$325,000	\$338,000
	Minor Injury	3.77	\$65,000	\$245,050
	Possible Injury	5.07	\$35,000	\$177,450
	Property Damage Only	20.41	\$7,400	\$151,034
	Total			
Secondary Road	Fatal	0.91	\$4,500,000	\$4,095,000
	Major Injury	3.77	\$325,000	\$1,225,250
	Minor Injury	9.62	\$65,000	\$625,300
	Possible Injury	10.01	\$35,000	\$350,350
	Property Damage Only	33.02	\$7,400	\$244,348
	Total			

Primary=Iowa DOT maintained; Secondary=county maintained

As shown, great cost benefits are to be expected with either approach taken. The benefits with the systematic approach were approximately three times higher than those with the targeted approach. However, this is a result of treating 20 times the number of intersections.

These values were used along with the cost to install rumbles on each minor approach of these intersections, and, then, the values were utilized to determine an expected B-C ratio for each scenario. The results of this B-C analysis are shown in Table 6.

Table 6. Expected benefit-cost ratios of TRS application scenarios

Intersection Road Type	Method	Crash Savings	Cost to Install Rumbles	Benefit-Cost Ratio
Primary Road	Treat All Intersections	\$13,078,260	\$992,500	13.177
	Treat Top 5% of Intersections*	\$3,836,534	\$57,500	66.722
Secondary Road	Treat All Intersections	\$18,826,912	\$5,095,000	3.695
	Treat Top 5% of Intersections*	\$6,540,248	\$285,000	22.948

Primary=Iowa DOT maintained; Secondary=county maintained

*Top 5% of highest crash intersections used in the analysis for Iowa from 2016 through 2020

As seen from the values, all scenarios would expect a B-C ratio greater than 1.2 (the value above which the Iowa DOT suggests it makes it a cost-effective project), therefore making it a sound investment. It should be noted that when taking a more targeted approach, a much better return on investment would be seen, with B-C ratios of the more targeted approach being five to six

times greater than for the systematic approach. One limitation to this analysis is that most studies that have evaluated TRS have them installed in locations that had a crash issue, while this B-C study included all intersections. When a site does not have a demonstrated crash history or risk factors present, the benefit may be overestimated. Unfortunately, a CMF does not yet exist based solely on data from a state that systematically applies TRS to intersection installation sites.

5. SUMMARY AND CONCLUSIONS

Transverse rumble strips are a proven treatment to help reduce crashes at rural stop-controlled intersections where drivers failing to stop is an issue. Failure to stop may be due to factors such as fatigue, distraction, and sight distance or weather issues (McGwin and Brown 1999, Campbell et al. 2004, Keay et al. 2009). Research has shown reductions in crashes ranging from about 20% to 40% at stop-controlled intersections after the installation of TRS. TRS have also been found to reduce driver speeds in the approaches to intersections in the range of 1 mph to 5 mph.

While effective, concerns often need to be taken into account with the installation and use of TRS, and noise is one of the primary concerns. Some states combat noise by choosing to not place TRS near residential areas or a set distance from residences. Research has also shown using a shallower depth rumble results in lower external noise while still producing adequate internal vehicle noise to be effective. In addition to different mill depths, researchers are investigating shallower, partially epoxy-filled TRS (Hurwitz et al. 2019). However, an optimal depth-noise ratio has not been well established.

Concerns about motorcyclists and bicyclists traversing the rumbles have not been studied; however, some states use a wheel path design for their TRS, which allows space for cyclists to safely avoid traversing them, or provide at least 4 ft of paved shoulder or 4 ft of pavement without TRS for cyclists to utilize.

Paved shoulders might also be an installation consideration for some rural Iowa locations with Amish populations. While not studied, Iowa's Amish may well find TRS to be a concern if forced to traverse them with horse and buggy.

Additional concerns that are often voiced have so far been shown to be unfounded. For instance, research has found no increase in erratic maneuvers (Miles et al. 2006 and Tang et al. 2016) nor issues related to road maintenance (FHWA 2015b, FHWA 2016, Coffey and Park 2016).

A synthesis of state DOT policies was conducted through a search of policies published online as well as through a survey that was sent to state DOT safety engineers through the AASHTO Safety Committee listserv. Seven states in addition to Iowa were found to have published policies that could easily be accessed. While 25 DOTs responded to the survey, only two of the states did not allow for TRS in advance of rural stop-controlled intersections, but it was mainly due to the associated noise issues.

For the states that allowed TRS, most did not take a systematic approach to TRS installation at stop-controlled intersections. All but two had less than 25% of their rural county paved intersections with TRS currently installed. From the responses, only North Dakota and South Dakota took a more systematic approach to TRS installation.

Four states specifically required a history of focus crash types before installing, while an additional nine noted they often used crash history. A systemic-like approach was taken by states

such as Maryland, Missouri, Ohio, and Wisconsin, which looked at sites with risk factors that increased the likelihood of a ran stop sign crash occurring. Some of the risk factors included sites with inadequate stopping sight distance or intersections that followed a long approach.

To address noise, some states require that rumbles be placed a minimum distance from homes; however, only two states noted that they required a certain distance from homes. South Dakota also recommends consideration of rumble strips that reduce noise, such as sinusoidal rumbles, if they are to be placed within 500 ft of a home. It should be noted that, while sinusoidal rumble strips have been found to have reduced exterior noise in centerline and edge line applications, TRS applications have not been studied. Due to the limitations of the equipment currently available, the milling of full-lane sinusoidal TRS is not likely feasible. In addition, the cost of installation is likely to be up to 1.65 times more expensive than that of traditional TRS designs based on cost data for edge line and centerline sinusoidal rumble strips (Staats et al. 2020).

Six states required other less intrusive countermeasures be tried before TRS were installed. Common countermeasures considered included removing sight obstructions, doubling up stop and advance warning signs, oversized signs, flags or flashing beacons on advance warning or stop signs, on-pavement signing, LED stop signs, intersection lighting, and overhead flashing beacons.

Finally, an economic analysis was conducted to determine the estimated B-C ratios of implementing TRS in Iowa. This included a systematic approach as was proposed in Baylee's Bill versus a more targeted approach treating the top 5% of high-crash locations among the intersections of interest that do not currently have TRS.

The analysis found that, while both approaches were economically sound investments with B-C ratios over 3 for all scenarios, the ratios were five to six times larger for the targeted approach. However, the CMF utilized for this analysis was most appropriate for locations with a demonstrated failure-to-yield crash history. Therefore, the estimated reductions may be smaller at sites without a history of crashes or higher for ones that actually may be at high risk for crashes occurring. Therefore, the benefits of the estimated B-C ratios may be overestimated or underestimated for any particular location.

National guidance suggests TRS should be used sparingly in order to remain effective (Neuman et al. 2003). This is due to their effectiveness being dependent on them being out of the ordinary. Less intrusive methods, such as clearing obstructions, adding additional pavement markings, upgrading signing by doubling up signs, using oversized signs, or adding treatments that increase the conspicuity of the sign, such as beacons, flags, or flashing LEDs, can be tried before resorting to installing TRS (Harwood 1993 and Neuman et al. 2003).

Identifying potential sites for TRS can be done by looking at sites with a crash history; however, rural intersection crashes, and especially major injury and fatal ones, tend to be widespread and less likely to have sites with an expansive crash history and therefore lend themselves more toward a systemic approach.

A systemic approach like MnDOT (2017) suggests for selecting sites for TRS installation finds the sites that are at high risk for ran-stop-sign crashes occurring due to having multiple risk factors present and treats those sites. Therefore, a targeted approach that identifies sites for installation of TRS through a combination of both a traditional hot spot and systemic screening will likely lead to the largest safety benefits, given this can identify the sites that have a crash history as well as those that are at highest risk for future crashes to occur.

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APPENDIX: SURVEY



Default Question Block

A study is being conducted by the Institute for Transportation at Iowa State University for the Iowa Department of Transportation with a goal of evaluating best practices related to the implementation of transverse rumble strips (TRS) in advance of rural stop controlled intersection. As part of this project, the team is looking to gain insight into other state's policies related to the application of TRS in advance of these rural stop controlled intersections.

The following questions aim to gather information on any policies your state may have related to TRS at stop controlled intersections, as well as any rationale that may be used to support these policies. This survey should take no more than 10 minutes. We thank you for your time in helping us to gain this valuable information. If you have any questions or concerns, please feel free to reach out to the study PI, Nicole Oneyear noneyear@iastate.edu.

Does your state allow for the use of transverse rumble strips in advance of rural stop controlled intersections?

Yes

No

Unsure

TRS Allowed Questions

Does your agency have a published policy on when TRS can be utilized in advance of rural stop controlled intersections?

- Yes
- No
- Unsure

Can you briefly describe the policy (e.g. must try other countermeasures, only if so many feet from homes, only at high crash locations, only roads of certain volumes, only high speed roads, etc.) or provide a link to the policy if it is publicly available?

If you had to roughly estimate, what percentage of your county paved rural stop controlled intersections currently have TRS installed?

- Less than 25%
- more than 25%, but less than 50%
- more than 50%, but less than 75%
- more than 75%

Does your agency require a history of failure to yield crashes before installing TRS at rural stop controlled intersections?

Yes

No

Other (please describe)

Does your agency require other countermeasures be tried before installing TRS at rural stop controlled intersections?

Yes

No

Unsure

Please list any of the countermeasures your agency requires be tried before installing TRS.

Does your agency have a policy on how close to homes and/or businesses TRS may be placed at rural stop controlled

intersections ?

Yes

No

Unsure

What is the minimum distance from homes that your agency allows TRS to be placed?

Has your state ever filled in transverse rumble strips?

Yes

No

Unsure

What has typically led to your state filling in transverse rumble strips.

Please check which State you represent.

Alabama

Alaska

Arizona

Arkansas

California

Colorado

Connecticut

Delaware

Florida

Georgia

Hawaii

Idaho

Illinois

Indiana

Iowa

Kansas

Kentucky

Louisiana

Maine

Maryland

Massachusetts

Michigan

Minnesota

Mississippi

Missouri

Montana

Nebraska

Nevada

New Hampshire

New Jersey

New Mexico
New York
North Carolina
North Dakota
Ohio
Oklahoma
Oregon
Pennsylvania
Rhode Island
South Carolina
South Dakota
Tennessee
Texas
Utah
Vermont
Virginia
Washington
West Virginia
Wisconsin
Wyoming
Washington D.C.

If we were to have follow-up questions, would you be willing to be contacted through phone or e-mail?

Yes

No

Follow up contact info

Please list an e-mail address we could use to follow up.

Please list a phone number we could use to follow up.

TRS Not Allowed Questions

Please list any reasons your agency does not allow for the use of transverse rumble strips in advance of rural stop controlled intersections? (e.g. noise, prefer other countermeasures to be used, adverse impacts to non-motorized users)

Did your state formerly have a transverse rumble strip policy?

Yes

No

Unsure

Has your state ever filled in transverse rumble strips?

Yes

No

Unsure

What has typically led to your state filling in transverse rumble strips.

Please check which State you represent.

Alabama

Alaska

Arizona

Arkansas

California

Colorado

Connecticut

Delaware

Florida
Georgia
Hawaii
Idaho
Illinois
Indiana
Iowa
Kansas
Kentucky
Louisiana
Maine
Maryland
Massachusetts
Michigan
Minnesota
Mississippi
Missouri
Montana
Nebraska
Nevada
New Hampshire
New Jersey
New Mexico
New York
North Carolina
North Dakota
Ohio
Oklahoma
Oregon
Pennsylvania
Rhode Island
South Carolina

South Dakota
Tennessee
Texas
Utah
Vermont
Virginia
Washington
West Virginia
Wisconsin
Wyoming
Washington D.C.

If we were to have follow-up questions, would you be willing to be contacted through phone or e-mail?

Yes

No

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