Final Report

EVALUATION OF NON-FREEWAY RUMBLE STRIPS - PHASE II



Prepared for:
Michigan Department of Transportation
Division of Research

Prepared by:
Wayne State University
Transportation Research Group

March 31, 2015

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Technical Report Documentation Page

1. Report No. RC-1627	2. Government Accession No. N/A	3. MDOT Project Manager Mary Bramble
4. Title and Subtitle EVALUATION OF NON-FREEWAY RUMBLE STRIPS – PHASE II		5. Report Date March 31, 2015
		6. Performing Organization Code N/A
7. Author(s) Tapan K. Datta, Peter T. Savolainen, Timothy J. Gates, Jonathan J. Kay, Nicholas B. Nicita, Sahadev Parajuli, Jacob Finkelman		8. Performing Org. Report No. N/A
9. Performing Organization Name and Address Wayne State University 5050 Anthony Wayne Drive Detroit, Michigan 48202		10. Work Unit No. (TRAIS) N/A
		11. Contract No. 2013-0070
		11(a). Authorization No. Z1
12. Sponsoring Agency Name and Address Michigan Department of Transportation Research Administration 8885 Ricks Rd. P.O. Box 30049 Lansing MI 48909		13. Type of Report & Period Covered Final Report 2/8/2013 to 3/31/2015
		14. Sponsoring Agency Code N/A
15. Supplementary Notes None		

16. Abstract

MDOT's rumble strip program for two-lane high speed rural highways was initiated in 2008 and continued through 2010. This program included implementation of centerline rumble strips (CLRS) on nearly 5,400 miles of two-lane high speed roads that MDOT maintains. This program presented an opportunity to perform a comprehensive evaluation of safety performance of rumble strips, especially CLRS. A two-phase evaluation study of the program was launched to estimate the driver behavioral and performance improvement in the presence of CLRS on two-lane high speed highways and also perform a system-wide "Before" and "After" study of target traffic crashes. The driver behavior-related study and collection of the three years' "Before" crash data and analysis was performed in Phase I (OR09084A) and the Phase II study was performed to collect the three years of "After" crash data, a program evaluation study, and benefit-cost analysis. The crash analysis indicated statistically significant reductions in all target crashes including, head-on, sideswipe opposite and run-off-the-road left. The study of crashes and their severity resulted in the reduction in fatal and all categories of injury crashes including a 47% reduction in total target crashes and a 51% reduction in target fatal crashes. An economic analysis of the rumble strip program resulted in a benefit-cost ratio of the program to be in the range of 58:1 to 18:1 based on discount rate assumptions of 2% and 10%, respectively. A road user survey indicated strong agreement among the respondents that CLRS is a beneficial safety improvement program.

17. Key Words Centerline Rumble Strips, Rumble Strips, Lane Departure Crashes, Program Effectiveness, Benefit-Cost Ratio			18. Distribution Statement No restrictions. This document is available to the public through the Michigan Department of Transportation.
19. Security Classification - report Unclassified	20. Security Classification - page Unclassified	21. No. of Pages 75	22. Price N/A

ACKNOWLEDGEMENT

The authors would like to recognize the following individuals for providing guidance and other valuable information or insight to this project as a part of Research Advisory Panel (RAP) and/or Focus Group member:

- Mary Bramble, MDOT, Project Manager
- Kim Ault, MDOT
- Mark Bott, MDOT
- Erin Chelotti, MDOT
- Lynette Firman, MDOT
- John Richard, MDOT
- Michael Townley, MDOT
- Jill G. Morena, MDOT
- David Morena, FHWA
- Kevin Kennedy, MDOT
- Curtis Bleech, MDOT
- Greg West, Oakland County
- Tim Haagsma, Kent County
- Karl Hanson, Wexford County
- Wayne Schoonover, Mason County

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EXECUTIVE SUMMARY

Driver fatigue, distraction, and/or inattention on two-lane high-speed undivided highways often leads to lane departure-related crashes and injuries. The use of continuous rumble strips along the centerline and/or shoulders of these highways can provide a supplemental warning to drivers, prompting appropriate corrective action (e.g., steering corrections, reduction in speed, etc.). This can help with crash avoidance, or reducing the severity should a crash occur.

In 2008, the Michigan Department of Transportation (MDOT) began a major rumble strip installation program to help alleviate lane departure crashes on rural non-freeway state trunklines. This initiative continued through 2010. The program included the installation of both Shoulder Rumble Strips (SRS) and Centerline Rumble Strips (CLRS) on all MDOT, rural, non-freeway highways with posted speed limits of 55 mph and appropriate paved lane and shoulder widths.

In order to perform a comprehensive evaluation of the effects of the installed rumble strips, MDOT initiated a two-phase evaluation study. This evaluation study primarily focused on safety effectiveness of CLRS, since the effectiveness of SRS had previously been established through numerous nationwide research and studies.

As a part of the Phase I study *(1)*, three years of "Before" (before CLRS installation) period crash data was collected and analyzed. Additionally, "Before" and "After" data was collected to evaluate driver behavior, noise propagation when in contact with CLRS, and short-term pavement performance. The Phase II study, which is the primary focus of this report, includes the analysis of three years of "After" period crash data, "Before" and "After" crash study, road user and MDOT personnel surveys regarding the perceived effectiveness and impacts on pavement, the economic analysis of rumble strips, and the estimation of crash reduction factors for rumble strips as a treatment for lane departure crashes.

There were a total of 5,400 miles of two-lane high speed state trunklines which had CLRS treatments applied during the years 2008-2010. However, after eliminating the gaps in CLRS due to intersections, urbanized areas, and other roadway features that required creating gaps in the CLRS, the result was 4,214 miles of roadway segments (net) with CLRS that were studied as a part of this Phase II study. Candidate crash data, consisting of crashes during the "Before" or "After" periods, were reviewed manually by the researchers to identify target crashes. A target crash is defined as a crash involving at least one vehicle crossing or encroaching on to the centerline, resulting in a crash. It is thought that the presence of CLRS could assist in crash avoidance or severity reduction. The final set of target crash data excluded all crashes with snowy or icy pavement as a contributing factor, since the difference of snowfall between the "Before" and "After" periods, could potentially introduce bias in the crash analysis results.

A safety performance analysis revealed a total of 2,488 "Before" and 1,306 "After" target crashes with regards to the CLRS installation period. The crash analysis indicated statistically significant reductions in all target crashes, including head-on, sideswipe opposite, and single vehicle run-off-the-road. The study of crash severity resulted in the reduction in fatal and all categories of injury crashes (Table ES-1).

Table ES-1. "Before and After" Safety Performance

CRASH TYPE OR SEVERITY	THREE-YEAR TARGET CRASH FREQUENCY		PERCENT REDUCTION IN TARGET CRASHES
	"BEFORE" PERIOD	"AFTER" PERIOD	
Angle	13	3	76.92%
Head-On	240	118	50.83%
Sideswipe Opposite	365	161	55.89%
Sideswipe Same	121	68	43.80%
S.V. Run-Off-the-Road	1,729	928	46.33%
Fatal	83	40	51.81%
A	237	139	41.35%
B	353	177	49.86%
C	381	206	45.93%
PDO	1,434	744	48.12%

The reductions in target crash types including "Head-on", "Sideswipe Opposite", "Sideswipe Same", and 'Single Vehicle Run-Off-the-Road", post CLRS installation, were statistically significant and ranged from 43% to 55%.

A study of the safety impact of CLRS across various traffic volume (AADT) groups and crash factors also indicated statistically significant crash reductions. Passing-related target crashes were reduced by 47%, those occurring on wet pavement experienced a reduction by 54% and others that involved impaired drivers due to alcohol or drugs were reduced by 35%.

An economic analysis was performed to determine the estimated cost benefit ratio of CLRS treatments on two-lane high speed rural highways in Michigan. Using the total target crashes identified in the “Before” and “After” periods and the cost per unit crash, an estimated total safety benefit of $79,571,500 over three years was calculated. Utilizing an estimated Equivalent Uniform Annual Benefit of $26,523,833, the economic analysis indicates the implementation of CLRS on two-lane high speed state highways will yield benefit to cost ratios of approximately 58 with a 2% and 18 with 10% discount rates, respectively. A sensitivity analysis was performed using discount rates of 2% to 10%. A range of benefit/cost ratio data is presented in the report to allow future users to choose the discount rate the agency wants to use and be able to estimate the appropriate benefit/cost ratio.

A road user survey was also performed to help gain valuable insight on the public’s perception on the use of CLRS. The survey indicated strong support for the use of CLRS as a safety measure. A survey of MDOT pavement design and maintenance personnel was also conducted and showed that the majority of staff strongly agree that the installation of CLRS improves safety, but 61% noted their design or maintenance strategy changes for a road with CLRS.

I. INTRODUCTION AND BACKGROUND

Driver fatigue, distraction, and/or inattention on two-lane high-speed undivided highways often lead to lane departure-related crashes and injuries. The use of continuous rumble strips along the centerline and/or shoulders of these highways can provide a supplemental warning to drivers, prompting appropriate corrective action (e.g., steering corrections, reduction in speed, etc.) helping in crash avoidance, and reducing the severity, if a crash occurs.

Continuous longitudinal rumble strips placed along the roadway edge or centerline are used by transportation agencies as a means of reducing lane departure crashes and injuries. When rumble strips are encountered by distracted or drowsy drivers, they provide both a tactile and audible warning. In 2008, MDOT began a major rumble strip installation program to help alleviate lane departure crashes on rural non-freeway state trunklines. This initiative continued through 2010. The program included the installation of both Shoulder Rumble Strips (SRS) and Centerline Rumble Strips (CLRS) on MDOT, rural, non-freeway highways with posted speed limits of 55 mph. SRS were also installed on roadways with shoulders of at least 6-foot width. CLRS were installed at all candidate highways, except at intersections and near urbanized areas. This rumble strip program is the largest of its kind in the United States. As such, it is important to carefully evaluate the impacts of the program on safety, operations, and pavement durability.

In order to perform a comprehensive evaluation of the effects of the installed rumble strips, MDOT initiated a two-phase evaluation study. The Phase I study *(1)* included:

- Identification and analysis of three years of “Before” period crash data
- Field studies of driver behavioral data “Before and After” CLRS installation, including driver operational data in the presence of bicyclists
- Study of noise propagation resulting from contact with CLRS and SRS
- Analysis of preliminary pavement performance between the periods “Before and After” CLRS installations.

The Phase II study, which is the primary focus of this report, included:

- Collection and analysis of three years of “After” period crash data (“Before” period data were collected in Phase I)

- Collection and analysis from pavement maintenance and design personnel regarding the functional effectiveness of rumble strips and any information observed about the impact on pavement performance
- Review of public opinion based upon initial perceptions, and current perception centered on crash and pavement performance data
- Economic analysis to determine benefit/cost ratios for rumble strip installations on highways stratified by various categories
- Estimation of crash modification factors for the use of rumble strips as a treatment for lane departure crashes
- Development of an informational report and a procedural guideline for state and local agencies regarding "How to implement rumble strips"

II. LITERATURE AND STATE-OF-THE-PRACTICE REVIEW

History and Earlier Studies

Pavement surface textures and treatments to provide both a tactile and audible warning to drivers have been in use for several decades. SRS have been used on freeways for many years, providing objective data regarding safety benefits. SRS have been applied as a means to alert drivers drifting out of the travel lane. Centerline rumble strips were initially implemented in the 1990's to prevent head-on collisions on two-lane rural highways. Early studies show centerline rumble strips installed on highway locations with a history of opposite direction collisions were found to be effective *(2)*. The use of centerline rumble strips on two-lane high-speed highways has increased over the past decade, but still has not experienced the level of implementation as shoulder rumble strips.

In 1994, Delaware's Department of Transportation (DOT) installed centerline rumble strips along a 2.9 mile section of roadway to determine the effectiveness of the installation of centerline rumble strips. This study performed a three-year "Before" and six-year "After" impact study and found average annual head-on collisions decreased by 90%. Other crashes caused by motorists crossing the centerline decreased by 60%, and no fatal crashes (at the study segments) occurred during the "After" study period *(3)*.

Colorado DOT installed 17 miles of centerline rumble strips on a winding, two-lane mountain highway in 1996. This study evaluated the effectiveness of centerline rumble strips by comparing 44 months of "Before" crash data and 44 months of "After" crash data. This study recorded a 22% reduction in head-on crashes and 25% reduction in side-swipe opposite crashes *(4)*.

Many other states have conducted or performed rumble strip effectiveness evaluation studies for the past three decades and documented similar safety performances. The use of CLRS and SRS on two-lane highways may require the consideration of roadway geometric characteristics.

The NCHRP-641 *(5)*, 2009, provided a summary of CLRS practices indicated that the size of CLRS varies from 12 to 24 inches in width, 5 to 8 inches in length, 3/8 to 3/4 of an inch in depth, and 10 to 48 inches in spacing.

Impact on Driver Behavior

Centerline rumble strips are designed to reduce run-off-the-road, head-on and opposite sideswipe crashes. Measures of effectiveness must include the vehicular lateral placement within the travel lane and vehicular encroachment onto or over the centerline. In the Phase I study *(1)* in Michigan, a video review of 60,396 vehicles "Before" the implementation of rumble strips and 41,301 vehicles "After" concluded that vehicles tended to be more centrally positioned within the lane when rumble strips were present. The study also concluded that encroachments across the centerline decreased significantly after the installation of CLRS for both at tangent and curvature locations *(1)*.

Pennsylvania also investigated the effect of centerline rumble strips on lateral vehicle placement on two-lane highways using a before-and-after observational study. They observed 387 vehicles before implementing centerline rumble strips and 449 vehicles after and concluded the vehicular mean lateral placement shifted 5.5 inches away from the roadway centerline for 12 foot lanes and 3 inches away for 11 foot lanes *(6)*.

Impact on Crashes

Many studies have been performed in various states to evaluate the crash reduction characteristics of CLRS. Previous research studies used the Naïve before-and-after method, the Empirical Bayes (EB) method, and a meta-analysis method to determine the effectiveness of centerline rumble strips in reducing lane departure crashes. The Naïve before-and-after method consists of a comparison of crashes before-and-after treatment, but may suffer from regression to mean effect, if one or more of the following are present:

1. Treatment was applied to high crash (target) locations only
2. If the crash data were available for a limited period (generally less than 2 to 3 years) for that "After" study period

The EB method is appropriate if both of the noted factors above are present. In this method, the expected number of crashes for the "After" period is estimated using the parameters from a control group. The meta-analysis method combines different studies and compares and contrasts the results to identify a common statistical measure.

A safety evaluation study by Sharma, et al. *(7)* performed a comparison of various methods of evaluation of traffic crashes, including Naïve "Before and After" (B&A), control group, and EB method. It concluded that where 3 to 5 years of "Before" and "After" data is available and no significant site-specific changes were made, beside the treatment being evaluated, the result of the B&A evaluation study yielded reliable results.

Kansas investigated the effectiveness of milled-in centerline rumble strips in reducing crossover crashes using both the Naïve before-and-after and EB methods over two sections totaling 26 miles of roadway. The Naïve before-and-after method for the first section consisted of a "Before" and "After" period of 5.5 and 4.4 years. The second section consisted of a "Before" period of 7.4 years and an "After" period of 2.5 years. The Naïve before-and-after method showed an overall 50% reduction in the total number of crashes and a 92% reduction in crossover crashes. The EB method showed an overall 49% reduction of the total number of crashes and an 89% reduction of crossover crashes *(8)*.

Persaud, et al. *(9)* performed a study that evaluated the effectiveness of centerline rumble strips along 210 miles of roadway among seven states with an average daily traffic volume of 8,829 before treatment and 9,668 after, using the EB method. The analysis of crash data showed a 14% reduction in all crashes, 15% reduction in injury crashes, 21% reduction in head-on and opposite sideswipe crashes, and a 25% reduction in injury crashes involving a head-on or opposite sideswipe crash *(9)*.

Karkle, Rys, and Russell *(10)* performed a meta-analysis of effectiveness data from several published and unpublished studies including Naïve before-and-after, EB, and comparison methods and observed percent reductions for crossover crashes ranging from 12% to 85%. Even though the results are not consistent, the study concluded that the centerline rumble strips are an effective countermeasure to alleviate crossover crashes.

While the studies vary in terms of sample size and time of pre and post periods, the results are similar. For example, crossover crash reduction was reported by various states as follows:

Kansas	-	69%
Minnesota	-	43%
New York	-	60%
Oregon	-	70%

Crossover fatal and severe injury crash reductions – 49% in Washington, 45% in Kansas, 73% in Minnesota, 44% in Pennsylvania.

Impact on Bicyclists

Although there is no evidence of an increase in bicycle-involved crashes associated with centerline rumble strips, there are reported concerns from the bicycle community. Bicyclists rarely need to cross a centerline rumble strip, but the presence of the rumble strip may cause vehicles to move away from the centerline to avoid contact with the rumble strip, potentially moving these vehicles closer to bicyclists who may be traveling on the outer edge of the lane *(2)*.

A field study to determine driver behavior in the presence of bicyclists was conducted on a rural, two-lane highway with a posted speed of 55 miles per hour, with a lane width of 11 feet, and a shoulder width of 4 feet. The highway consisted of segments containing both with and without centerline rumble strips. The study concluded that out of 1,197 vehicle-bicycle passing events, on both the segments, there was a 7.9% reduction in vehicles contacting the centerline when passing a bicyclist and a 3% reduction in vehicles crossing at least halfway into the opposing lane when passing a bicyclist on the segments with centerline rumble strips *(1)*.

Impact on Pavement Deterioration

Limited research exists pertaining to pavement deterioration caused or accelerated by the installation of centerline rumble strips. Although there is no substantial evidence of an increase in pavement distress, the perception is generally that it does. Colorado performed subjective visual field assessments for five years and determined rumble strips did not have any significant detrimental effect on pavement life. Any sand or water accumulated in the grooves is cleared by the air movement caused by passing traffic *(4)*.

A review using MDOT pavement imagery data was performed to determine the impact of short-term pavement performance due to the installation, conducted over a two-year period. The study included random samples of 275 miles of highway with centerline rumble strips and 182 miles without. The imagery review resulted in an average increase of 3.45 transverse cracks per tenth of a mile before and after the installation of centerline rumble strips, whereas the average increase where no centerline rumble strips were installed was 3.79. The review demonstrated virtually the same rate of increase in the frequency of cracks per tenth of a mile, and concluded centerline rumble strips did not create any adverse impact on the short-term pavement performance *(1)*.

Impact on Noise

Although centerline rumble strips provide benefit to roadway safety, the noise produced when vehicles contact them may be undesirable for local residents *(1)*. Multiple studies have been performed that measure the volume of the generated noise, however an unmeasured factor that should be noted is that the sound produced has a unique staccato resonance that contributes to the undesirable nature of the noise.

Kansas investigated the levels of noise created by centerline rumble strips by verifying the effects of speed, vehicle type, strip shape, and distance from the noise source by utilizing the controlled pass-by method. Data was collected at 10 different locations with a posted speed limit of 65 miles per hour. The study concluded that centerline rumble strips substantially increase levels of ambient noise, and the noise level is a function of travel speed and type of vehicle *(11)*.

A controlled field study was performed in the Phase I Michigan study *(1)* to evaluate increases in roadside noise produced by centerline rumble strips on rural, two-lane highways as a function of rumble strip depth and pavement surface type. The test vehicle contained a stationary roadside noise meter and performed the pass-by method at 12 different locations with a posted speed limit of 55 miles per hour. The study concluded the mean increase in noise level where centerline rumble strips were present, compared to areas without, is an 8.1 dBA increase, and that the rumble strip depth is the biggest factor affecting the amount of noise produced by vehicles crossing it *(1)*.

Conclusion from Literature

Results from previous research studies have allowed for the following conclusions pertaining to the effectiveness of centerline rumble strips:

- Impact on Driver Behavior
  - Vehicles tend to be more centrally positioned within the lane
  - Major encroachments across the centerline decrease for both tangent segments and horizontal curves
  - Lateral placement is shifted away from the roadway centerline where CLRS is present
  - Passing behavior was not impacted by CLRS presence

- Impact on Crashes
  - Various degrees of crash reductions for lane departure-related crashes have been confirmed by past evaluation studies
  - Reduction in injury and fatal crashes have been documented
  - 47% reduction in total target crashes
  - 44% reduction in fatal and severe injury crashes

- Impacts on Bicyclists
  - No evidence of an increase in bicycle-involved crashes
  - Vehicles tend to move away from the centerline with CLRS
  - Vehicular traffic moves closer to bicyclists who may be traveling to the outer edge of the travel lane

- Impact on Pavement Deterioration
  - Visual field assessments concluded rumble strips did not have any significant short-term detrimental effect on the pavement life
  - Any sand or water accumulated in the grooves is cleared by air movement caused by passing traffic
  - Imagery reviews concluded that there was no adverse impact on the short-term pavement performance

- Impact on Noise
  - Pass-by method showed increases in the level of ambient noise
  - Noise is affected by both the speed and type of vehicle
  - Rumble strip depth is the biggest factor affecting the amount of noise produced due to CLRS. Spacing can also alleviate noise in certain situations *(12)*.

III. CRASH ANALYSIS METHODOLOGY

Performing an effectiveness evaluation of a system-wide program requires methodical data collection, use of appropriate independent and dependent variables, and statistical testing that provides answers to questions related to effectiveness. The evaluation of driver behavior and performance with the use of CLRS was performed as a part of the Phase I study *(1)*. The collection of pre-installation system-wide crash data was also collected. They were further reviewed and the post CLRS implementation crash data collection and analysis was performed in Phase II.

In order to conduct an appropriate in-place safety performance evaluation of the 2008 CLRS program in Michigan, several levels of data were required to be collected, analyzed, and reduced. While the study methodology will be described in greater detail in the sections that follow, this multiple step process is outlined in Figure 1.

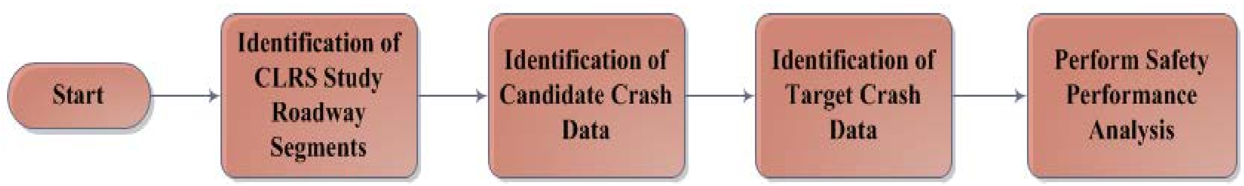


Figure 1. Safety Performance Evaluation Methodology

The first step was to identify sections of highway on which the CLRS safety treatments were applied which formed the basis of this study. In the context of the study, these sections of highway serve as the study road segments over which historical crash data will be analyzed to determine the potential impact of the safety treatment.

Three years of pre and post CLRS installation crash data were collected for the entire verified CLRS roadway segments. Any crash that occurred on the roadway segments during the three years pre and post CLRS installation periods were selected as the “candidate” crashes that required further analysis in Phase II.

Finally, the subset of "target" crashes or those crashes whose outcome could potentially have been impacted by the presence of CLRS, were identified from the database of all candidate crashes.

2(a). Identification of CLRS Study Roadway Segments

Initially, MDOT Transportation Service Centers (TSCs) provided details of roadway segments which had CLRS treatments applied during the 2008-2010 implementation. It should be noted that the installation year and whether it was CLRS only, or CLRS in combination with SRS installation was determined. This information was developed into a database during Phase I. Upon analyzing initial segment data based on the restriping and construction contracts, inconsistencies were determined and appropriately corrected in candidate segments during Phase II.

After this initial review, the researchers performed a complete review of each segment via available satellite and street-level imagery, and MDOT's video-log files. This allowed for the identification of additional roadway segments which had geometry that did not include CLRS (such as divided highways) and the incorrect installation years. Such segments were subsequently removed from the database. Finally, the database of roadway segments was combined with the MDOT Roadway Sufficiency File database, from the basis of matching MDOT Physical Road (PR) numbers and associated beginning and ending mile points, in order to identify additional characteristics about each segment, including:

- Annual average daily traffic (AADT) estimates
- Percentage of trucks
- Lane width
- Shoulder width
- Number of lanes
- Presence of passing lanes
- Presence of no-passing zones

As a result, and illustrated in Figure 2, a database of CLRS study roadway segments was developed which could be used for the identification of candidate crash data.

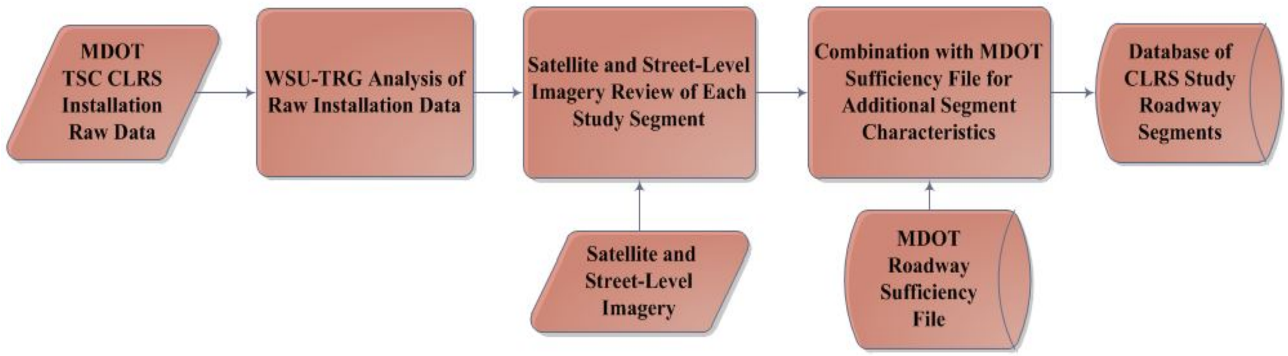


Figure 2. Identification of CLRS Study Roadway Segments

The final database included approximately 4,214 miles (over 1,394 road segments) of CLRS installed as a part of the statewide program. The final set of study segments includes only those roadway segments for which rumble strips were confirmed by satellite and/or street-level imagery. Table 1 shows the summary of study CLRS road segments by installation year.

Table 1. CLRS Study Segments by Installation Year and Presence of SRS

CLRS INSTALLATION YEAR	CLRS ONLY (Miles)	CLRS AND SRS (Miles)	TOTAL (Miles)	AADT ESTIMATED AVERAGE (VPD)
2008	837	565	1,403	5,381
2009	947	284	1,230	4,585
2010	1,288	293	1,581	4,190
TOTAL	3,072	1,142	4,214	4,683

As noted in Table 1, approximately 73 percent of the study segments included the installation of CLRS only (3,072 miles), while the remaining approximately 27 percent included both CLRS and SRS (1,142 miles).

Table 2 shows the distribution of candidate CLRS as well as CLRS and SRS combinations per various levels of AADT groups. AADT data was obtained from the MDOT roadway sufficiency files for each of the relevant years "Before" and "After" period of CLRS installations.

Table 2. CLRS Study Segments by AADT Grouping

AADT ESTIMATE RANGE (VPD)	NUMBER OF SEGMENTS	TOTAL SEGMENT LENGTH (Miles)	MINIMUM SEGMENT LENGTH (Miles)	MAXIMUM SEGMENT LENGTH (Miles)
<2,500	389	1,572	0.051	21.74
2,500-5,000	473	1,402	0.027	12.43
5,000-7,500	320	838	0.066	12.69
>7,500	212	401	0.096	9.21
TOTAL	1,394	4,214	0.027	21.74

Consistent with the definition of MDOT's CLRS installation program, approximately 71 percent of CLRS were installed on roadways with estimated traffic volumes of 5,000 vehicles per day or less. It should be noted that included within the sample of study segments there were some undivided roadways which included four travel lanes (two lanes in each direction). These four-lane segments, along with additional two-lane road segments in more densely populated or urban regions, make up the majority of the higher-volume segments.

2(b). Identification of Candidate Crash Data

The first step of the crash data collection process was to identify all of the traffic crashes which occurred on the study roadway segments during the appropriate pre-installation ("Before") or post-installation ("After") study periods. In the context of this study, prior research has shown that three years "Before" and three years "After" data is sufficient to provide an adequate sample to eliminate concerns regarding the regression to mean effect *(7)*. The program consisted of CLRS installation on all candidate road segments, and not on the basis of any site-specific high crash locations.

As the month of installation was not specifically known for each segment, crash data for the year of installation were excluded for this study to avoid any influence of construction period crashes in the overall evaluation study. Therefore, candidate crash data was collected based on the study periods identified in Table 3.

Table 3. Study Periods by Year of CLRS Installation

CLRS INSTALLATION YEAR	"BEFORE" PERIOD	"AFTER" PERIOD
2008	2005-2007	2009-2011
2009	2006-2008	2010-2012
2010	2007-2009	2011-2013

Given the study periods provided in Table 3, candidate crash data for the study segments were acquired by querying the yearly crash databases maintained by the Michigan State Police (MSP). This was completed by matching all crashes located within the study segments on the basis of MDOT PR Number and associated mile point data. Crashes were considered as a candidate crash if they met all of the following conditions:

- All crashes that occurred during one of the "Before" or "After" study periods identified in Table 3
- Crash location per MDOT PR Number and mile point fell within a study segment (as demonstrated in Figure 3)
- Crash occurred at a mid-block location (all intersection, interchange, and non-traffic area crashes were excluded)

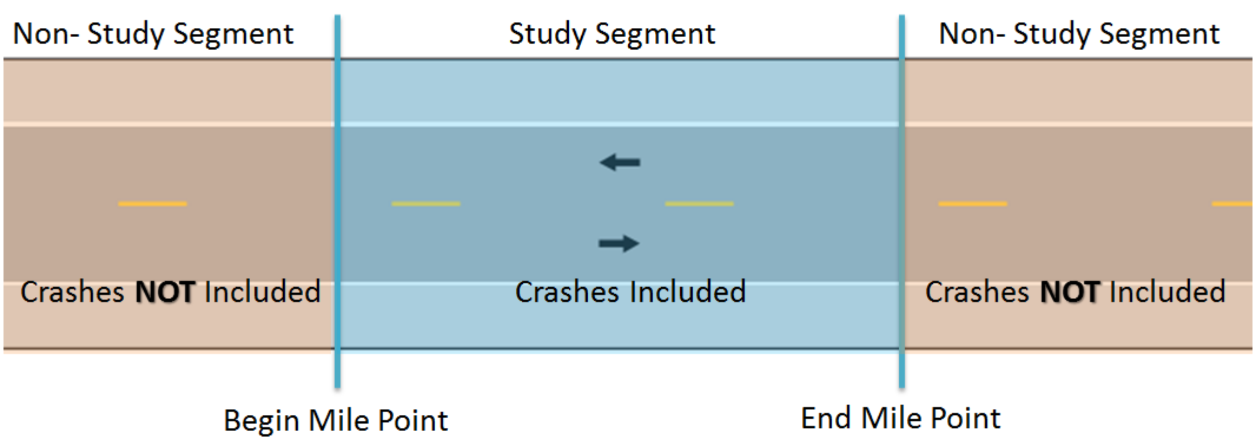


Figure 3. Inclusion of Candidate Crashes Based on Crash Location

It should be noted that the pool of candidate crashes were limited to those occurring at mid-block locations only since CLRS installations are generally not continued through intersections.

The intent of the safety treatments is designed to address roadway or lane departure-type crashes, which by definition occur only at non-intersection/interchange locations. Based on this methodology, a dataset of candidate crash data was identified and summarized by police-coded crash type as shown in Table 4.

Table 4. CLRS Candidate Crash Data by Police-Coded Crash Type

POLICE-CODED CRASH TYPE	THREE YEARS OF CRASH DATA BEFORE CLRS INSTALLATION		THREE YEARS OF CRASH DATA AFTER CLRS INSTALLATION	
	FREQUENCY	PERCENT OF TOTAL	FREQUENCY	PERCENT OF TOTAL
Angle	630	1.63%	409	1.20%
Head-On	584	1.51%	382	1.12%
Other	667	1.72%	609	1.79%
Rear End	1,934	5.00%	1,652	4.86%
Sideswipe Opposite	514	1.33%	329	0.97%
Sideswipe Same	541	1.40%	466	1.37%
Single Vehicle	33,830	87.42%	30,138	88.68%
TOTAL	**38,700**	**100%**	**33,985**	**100%**

The dataset of CLRS candidate crashes consisted of 38,700 crashes occurring during the three years "Before" installation of CLRS and 33,985 crashes occurring in the three-year "After" period. While the frequency of crashes in the "After" period was reduced compared to the pre-installation period, this may be attributable to changes in exposure (such as traffic volumes), regression to the mean, or other factors unrelated to the installation. An observation from Table 4 is the number of "angle" crashes as noted by responding police officers. Given the description of an "angle"-type crash where the initial angle of the two colliding vehicles should be perpendicular, it is difficult to imagine such crashes occurring with such frequency at non-intersection locations. To rectify such coding issues, a subsequent review of each crash report form was conducted.

2(c). Identification of "Target" Crash Data

A limitation in previous evaluations of CLRS and SRS is the identification of "target" crashes. In this context, a "target" crash refers to the subset of candidate crashes which may potentially be impacted by the presence of CLRS. Most prior evaluations have attempted to complete this data reduction process by only identifying crashes as target, if crash report coding fits certain criteria, such as:

- Single vehicle run-off-the-road crashes (left for CLRS and right for SRS)
- Head-on and sideswipe opposite-type crashes
- Fatal and severe injury crashes
- Derived "lane departure"-type crashes (based on harmful event codes noted within the crash report form data)

However, reducing candidate crashes to target crashes via an automatic screening process, such as the method described above, can involve limitations. Most notably:

- The process relies on the accuracy of police-coded crash data, which has been previously demonstrated to be sometimes unreliable and inconsistent, particularly with respect to crash type
- It may not include all of the types of crashes which may be impacted, positively or negatively. For example, coding sideswipe opposite type of crashes are sometimes miscoded as "Angle" crashes. Such a coding could provide an inaccurate perception, if police-coded inaccuracies are not resolved in the crash analysis process.

The research team performed a complete manual review of all 72,785 ("Before" and "After") crash report forms associated with each entry in the candidate crash database. In order to perform the manual review, crash report forms from MDOT's Traffic Crash Reporting System (TCRS) were downloaded.

The manual review process included identification using the written description and diagram portion of the UD-10 crash report form. Despite certain limitations related to the interpretability of the descriptions and diagrams, this is still the most detailed information reasonably obtainable relevant to each candidate crash. Based on the written description and diagram, reviewers identified "target" crashes which:

- Include at least one vehicle crossing the centerline and
- Could be affected by the presence of a CLRS

These are important distinctions because reviewing target crashes in this way can reveal significant additional findings about the impact of CLRS. For example, it may be expected that crashes coded as sideswipe same, rear-end, and “Other”-type could not be impacted by CLRS. However, given the large sample of crash data, some descriptions of types of crashes that are not anticipated to be impacted by CLRS, may reveal contradictory findings. As such, each crash in the candidate crash database was reviewed to determine if the crash was “target” or not, based on this definition. An example of a target crash diagram and narrative is shown in Figure 4.

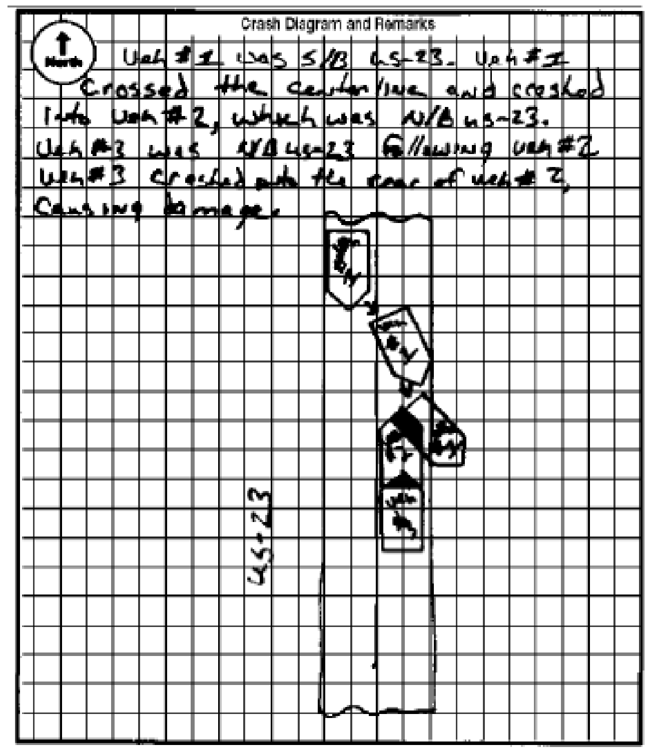


Figure 4. Example Target Crash UD-10 Diagram and Narrative

For all crashes identified as targets, based on the manual review, an additional review was conducted to ascertain whether the crash narrative was in contrast with one of the other fields of interest. While there are fields on the report form to indicate wet, icy, snowy, or slushy pavement, cases were identified where the officer noted one of these conditions in the narrative, but not in the pavement condition field. Similar instances were observed with respect to driver impairment and, in each case, the initial pavement condition and driver impairment codes were corrected. The manual review was also used to identify crashes that involved passing maneuvers by one of the crash-involved drivers.

Crash type was also verified as numerous cases were observed where the narrative contradicted the crash type code. A common issue was that crashes were classified based upon the position of vehicles at impact, rather than their pre-crash travel direction. A common example is a head-on or opposite-direction sideswipe being incorrectly classified as an angle crash. Table 5 provides a summary of target crashes, both by the initial police-coded crash type and the corrected crash type from the manual review.

This study involved identifying crashes where at least one vehicle crossing or encroaching the centerline and those that could be impacted by the presence of CLRS. The snow/icy pavement can influence such incidences and therefore, an increase or decrease in target crashes in any specific year could be influenced by annual snow fall. In order to eliminate this potential source of bias, target crashes in the study eliminated the crashes that included snowy or icy pavement as a contributing factor.

Table 5. CLRS Target Crashes (Three-Year) by Police-Coded and Corrected Crash Types

CRASH TYPE	CRASHES BY POLICE-CODED TYPE		CRASHES BY CORRECTED TYPE	
	"BEFORE" PERIOD	"AFTER" PERIOD	"BEFORE" PERIOD	"AFTER" PERIOD
Angle	74	14	13	3
Head-On	229	111	240	118
Other	40	37	16	22
Rear End	3	10	4	6
Sideswipe Opposite	288	148	365	161
Sideswipe Same	134	59	121	68
Single Vehicle	1,720	927	1,729	928
TOTAL	**2,488**	**1,306**	**2,488**	**1,306**

After the manual review process was completed, a total of 2,488 target crashes were identified for the period prior to rumble strip installation and 1,306 target crashes were identified during the post-installation period. As expected, the vast majority of target crashes involved single vehicle run-off-the-road-left, head-on, and opposite-direction sideswipe collisions. However, approximately 10 percent of the crashes during each period were comprised of improperly coded crash types. Table 6 shows the frequency of CLRS target crashes by the severity.

Table 6. CLRS Target Crashes by Period and Severity Level

CRASH SEVERITY	THREE-YEAR "BEFORE" PERIOD FREQUENCY	THREE-YEAR "AFTER" PERIOD FREQUENCY
Fatal	83	40
Injury	971	522
PDO	1,434	744
TOTAL	**2,488**	**1,306**

IV. INVESTIGATION OF WEATHER-RELATED FACTORS

The identification of target crashes that are expected to be influenced by the installation of CLRS eliminated crashes that had snowy/icy pavement as a contributing factor for both the "Before" and "After" period crashes. This is necessary to eliminate the potential influence of differing seasonal weather intensities year to year on target crashes. In order to investigate the variability between "Before" and "After" periods, a study of precipitation and snow fall characteristics were performed for the "Before" and "After" periods based on historical records maintained by National Oceanic and Atmospheric Administration's (NOAA).

Historical precipitation and snow totals were acquired for each study roadway segment from NOAA's annual climatological summary database. Totals were obtained for the weather stations nearest to each study segment during each year of the study period. The data from all stations within 50.0 miles of the centroid of each segment were averaged in order to estimate annual totals for both precipitation and snowfall (in inches) specific to that study segment. It should be noted that weather stations which were located greater than 50.0 miles from the centroid of any study segment were excluded from the analysis. A weighted-average was calculated for each MDOT region based on the length of centerline rumble strip miles installed in order to determine an appropriate value for analysis.

Table 7 shows the mileage of CLRS installed by region and the annual average precipitation and snowfall for both the "Before" and "After" periods used in this study.

Table 7. Weighted-Average Annual Precipitation and Snowfall by MDOT Region

MDOT REGION	CENTERLINE MILES	AVERAGE PRECIPITATION (IN)		AVERAGE SNOWFALL (IN)	
		BEFORE	AFTER	BEFORE	AFTER
Superior	1416.53	29.92	31.11	113.77	82.12
North	848.10	32.23	34.07	96.44	69.78
Grand	304.25	35.73	35.69	70.86	49.67
Bay	729.43	34.11	34.09	54.26	40.83
Southwest	464.95	40.80	38.46	65.70	43.87
University	406.23	36.95	37.10	44.65	33.52
Metro	44.26	35.88	34.74	44.91	35.84
All Regions	4213.75	33.47	33.98	84.19	60.76

Figures 5 and 6 show the precipitation and snowfall data for both the “Before and After” study periods by MDOT regions. This study confirmed that the exclusion of “snowy/icy pavement”-related target crashes were appropriate for the safety performance study due to regional snowfall differences between the “Before” and “After” periods.

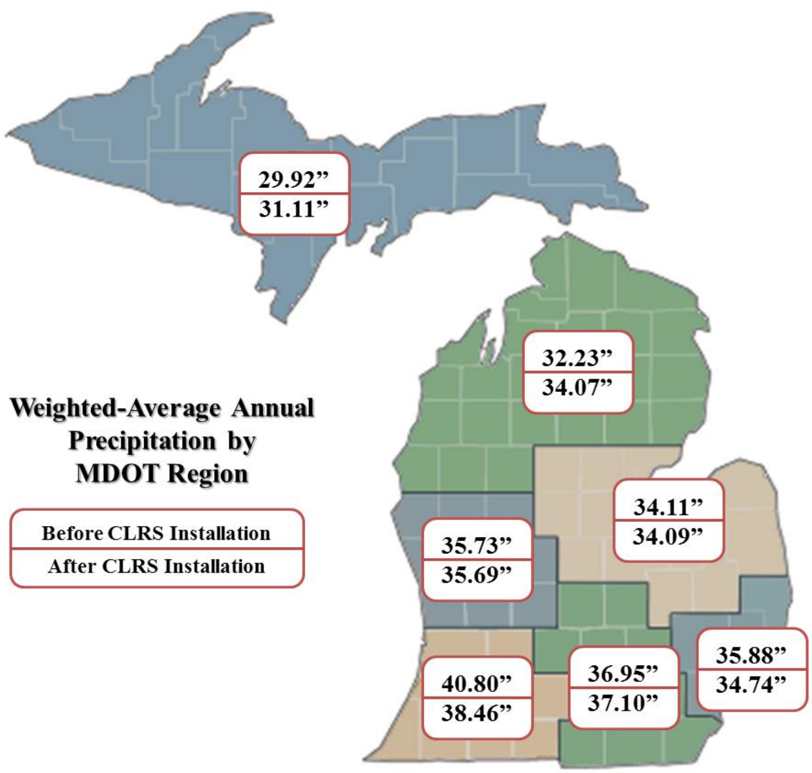


Figure 5. Weighted Average Precipitation by MDOT Region

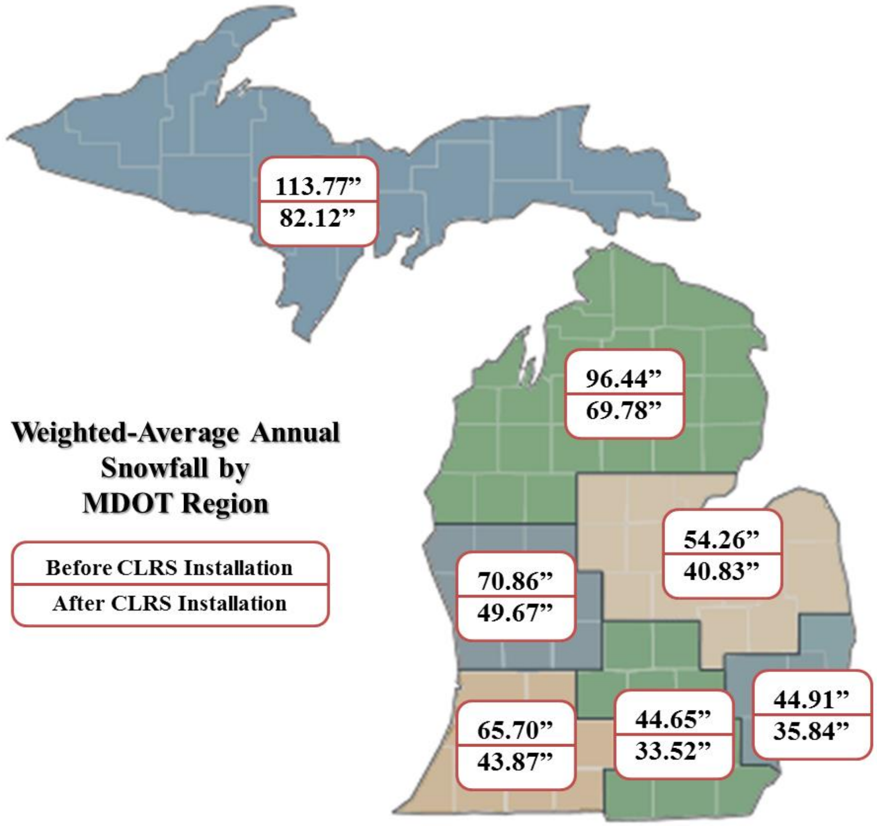


Figure 6. Weighted Average Snowfall by MDOT Region

V. SAFETY PERFORMANCE ANALYSIS

A “Before and After” safety performance analysis of the MDOT CLRS program was performed by observing the differences in crash frequencies “Before” and “After” the installation on the study road segments. In order to test the significance of noted percent reductions in target crashes, the expected accident frequency without treatment using the Poisson distribution (Figure 7) was applied as specified in the *FHWA Highway Safety Evaluation Procedural Guide (13).* The frequency of crashes in the pre-installation condition is compared with the percent change in crash frequency observed in the post-installation condition for varying levels of confidence. If the data point falls above the curve for the desired level of confidence, the percent change is significant, whereas if it falls below, it indicates a percent change which is not statistically significant. It should be noted that the results of this method are presented in Appendix I to this document.

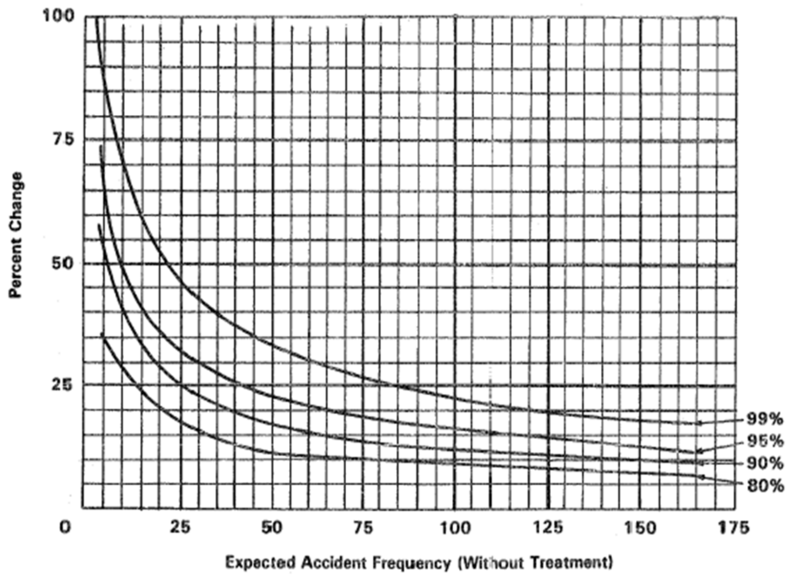


Figure 7. Poisson Curves for Expected Accident Frequency *(13)*

Table 8 presents this "Before and After" safety performance analysis of the CLRS initiative in Michigan, disaggregated by the severity level of injury in the target crash.

Table 8. "Before and After" Safety Performance by Severity Level

WORST INJURY IN CRASH	THREE-YEAR TARGET CRASH FREQUENCY		PERCENT REDUCTION IN TARGET CRASHES	STATISTICALLY SIGNIFICANT AT 95% LEVEL OF CONFIDENCE
	"BEFORE" PERIOD	"AFTER" PERIOD		
Fatal	83	40	51.81%	Yes
A	237	139	41.35%	Yes
B	353	177	49.86%	Yes
C	381	206	45.93%	Yes
PDO	1,434	744	48.12%	Yes
TOTAL	**2,488**	**1,306**	**47.51%**	**Yes**

From Table 8 it can be observed that the overall "Before and After" reduction in target crashes, after the implementation of the safety treatment, was approximately 48 percent. All of the percent reductions for each severity level were significant at a 95 percent level of confidence and the reductions were relatively consistent across all severity classifications. These results are supplemented by Table 9 which provides the same "Before and After" safety performance analysis disaggregated by the corrected crash type.

Table 9. "Before and After" Safety Performance by Corrected Crash Type

CORRECTED CRASH TYPE	THREE-YEAR TARGET CRASH FREQUENCY		PERCENT REDUCTION IN TARGET CRASHES	STATISTICALLY SIGNIFICANT AT 95% LEVEL OF CONFIDENCE
	"BEFORE" PERIOD	"AFTER" PERIOD		
Angle	13	3	76.92%	Yes
Head-On	240	118	50.83%	Yes
Other	16	22	-37.50%	No
Rear End	4	6	-50.00%	No
Sideswipe Opposite	365	161	55.89%	Yes
Sideswipe Same	121	68	43.80%	Yes
S.V. Run-Off-the-Road	1,729	928	46.33%	Yes
TOTAL	**2,488**	**1,306**	**47.51%**	**Yes**

As expected, other and rear-end type crashes did not demonstrate statistically significant percent changes after the installation of CLRS. However, there were statistically significant percent reductions for the specific types of crashes CLRS are designed to mitigate, including head-on, sideswipe opposite-direction, sideswipe same-direction, and single vehicle run-off-the-road crashes. These results presented in Table 9 are in general agreement with previous research, with the primary target crash types resulting in reductions of greater than 40 percent.

An additional study objective, given the system-wide implementation of CLRS in Michigan was to identify contributing factors to CLRS target crashes. By observing the differences in the target crash frequencies disaggregated by selected contributing factors in the pre- and post-installation periods, additional "Before and After" safety performance analyses were completed to discern the additional impacts of CLRS. The results of this "Before and After" analysis are presented in Table 10. Since contributing factors may overlap, and not all target crashes involved a contributing factor, the sum of target crash frequencies in Table 10 will not be equal to the total number of such target crashes.

Table 10. "Before and After" Safety Performance by Contributing Factor

CONTRIBUTING FACTOR	THREE-YEAR TARGET CRASH FREQUENCY		PERCENT REDUCTION IN TARGET CRASHES	STATISTICALLY SIGNIFICANT AT 95% LEVEL OF CONFIDENCE
	"BEFORE" PERIOD	"AFTER" PERIOD		
Passing	274	143	47.81%	Yes
Wet Pavement	452	208	53.98%	Yes
Snowy/Icy Pavement*	2,105	1,778	15.53%	Yes
Impaired Driver*	327	210	35.78%	Yes

* Not included in overall safety analyses presented previously.

The results of this safety performance analysis shown in Table 10 include several findings about CLRS performance in Michigan. Passing-related target crashes, where a vehicle voluntarily crossed the centerline in an attempt to pass and subsequently collide with another vehicle or object, observed a statistically significant reduction in frequency of greater than 47 percent. This finding is perhaps in contrast to the previous research in this area which has suggested that driver behavior does not significantly change in relation to passing maneuvers after the installation of CLRS. CLRS sometimes reduces risky passing behavior, despite this not being their primary intent. More rigorous analysis is required to determine the specific effect of CLRS on passing-related crashes (such as changing exposure). Additional research should be performed in this area of passing-related crashes, as it remains one of aspects about which not much is known.

Target crashes occurring on wet pavement also experienced a statistically significant reduction of almost 54 percent after the implementation of CLRS. This supports previous research which has suggested that the additional guidance, in terms of lane delineation, assists drivers in poor visibility conditions. Further, target crashes occurring on snowy or icy roads were also significantly reduced. However, this impact was much less at approximately 15 percent.

Target crashes which involved drivers who were noted as being impaired by the responding officer due to the influence of either alcohol or drugs were also significantly reduced after the implementation of CLRS. This reduction is similar to that of the overall results, which indicates that while the additional guidance from CLRS is assisting certain impaired drivers, there remain many who are still involved in lane departure crashes. More rigorous analysis is needed to determine the precise impacts of CLRS on impaired drivers, such as including the impact of changing exposure. The "Before and After" analysis performed further supports the use of CLRS as the treatment.

Another consideration related to evaluating the safety performance of the system-wide CLRS initiative is considering the impact in mitigating lane departure crashes on across various traffic volumes (AADT). While the definition of the MDOT CLRS program involved all two-lane rural non-freeways within their jurisdiction, the program included several highways which were in relatively more urbanized areas or involved four travel lanes (two in each direction). Table 11 provides the "Before and After" safety performance of the CLRS program disaggregated by ranges of mean AADT estimates for the entire study period (or the average of all six years for each segment).

Table 11. "Before and After" Safety Performance by AADT Range of Study Segment

MEAN AADT ESTIMATE RANGE (VPD)	NUMBER OF SEGMENTS	TOTAL SEGMENTS LENGTH (MILES)	THREE-YEAR TARGET CRASH FREQUENCY		PERCENT REDUCTION IN TARGET CRASHES	STATISTICALLY SIGNIFICANT AT 95% LEVEL OF CONFIDENCE
			"BEFORE" PERIOD	"AFTER" PERIOD		
<2,500	389	1,572	470	275	41.49%	Yes
2,500-5,000	473	1,402	828	427	48.43%	Yes
5,000-7,500	320	838	710	368	48.17%	Yes
>7,500	212	401	480	236	50.83%	Yes
TOTAL	1,394	4,214	2,488	1,306	47.51%	Yes

The results presented in Table 11 indicate that CLRS are performing at a similar level across all volume groups. The percent reductions in target crashes on a "Before and After" frequency basis were statistically significant across all volume groups, with reductions ranging from over 40 percent for the very low volume highways to greater than 48 percent for the higher volume highways. This indicates that CLRS are providing similar impacts, regardless of the traffic volume on the non-freeway roadway, at least across the relatively homogenous sample of highways observed as a part of this study. These results should be interpreted with caution as they do not consider the impact of potentially changing exposure or other unobserved or unaccounted for factors. In addition, the AADT estimates developed by MDOT, utilized as a part of this analysis, were derived from hourly counts performed by MDOT and may not reflect the actual volumes on the study road segments.

Crash Reduction Factors

The safety performance analysis of Michigan's CLRS implementation program, and past research and safety performance studies completed in other states, have generally indicated similar results. The following are the suggested target crash reduction factors that can be used by other road agencies in estimating expected safety benefits of CLRS on two-lane high speed rural highways:

- Total crashes - 47%
- K and A injury - 44%
- Side-swipe opposite - 55%
- Side-swipe same - 43%
- Single vehicle run-off-the-road - 46%

Use of the noted crash reduction factors should be limited to two-lane high speed highways.

VI. BENEFIT-COST ANALYSIS

The economic value of a safety treatment can be determined if the changes in crashes and injuries are statistically significant and the benefit to cost ratio of the safety benefits attributable to the countermeasure is greater than one. Therefore, as a part of this study a comprehensive economic analysis of the entire rumble strip implementation program in Michigan was performed.

MDOT project costs were used to determine the overall cost of the rumble strip program construction. Since the CLRS implementation program spanned over a three-year period (2008, 2009, and 2010), the costs were different. Also, various project costs were slightly different because some segments were treated with both CLRS and SRS, and some segments only included CLRS (Table 12). The cost of installing rumble strips is higher for concrete pavement as opposed to hot mix asphalt (HMA) pavements; therefore, the cost of installation is shown separately for concrete.

The installation cost by pavement type is shown in Table 13. The total statewide rumble strip installation cost for the MDOT program was $3,357,978. It is important to note that Michigan's entire rumble strip program was implemented based on 2003 specifications.

The average costs of CLRS and SRS installation on asphalt pavement were $0.12/ft. and $0.11/ft., respectively. Similarly, those on concrete pavement were $0.27/ft. and $0.17/ft., respectively.

A study of rumble strip installation costs, as reported by various states, was also performed. A summary of reported cost by various states is included in Appendix II.

Table 12. Estimated Cost of Rumble Strips (2008-2010) in Michigan

Estimated Cost for Centerline Rumble Strip				
Installation Year	**2008**			
Pavement Type	**Asphalt**		**Concrete**	
Installation Type	**Centerline Only**	**Shoulder and Centerline**	**Centerline Only**	**Shoulder and Centerline**
Segment Length (miles)	837.20	561.19	0.00	4.16
Total Segment Length (miles)	1402.55			
Cost/Installation Type	$530,451	$681,510	$0	$9,662
Cost/Pavement Type	$1,211,961		$9,662	
Total Cost	**$1,221,623**			
Installation Year	**2009**			
Pavement Type	**Asphalt**		**Concrete**	
Installation Type	**Centerline Only**	**Shoulder and Centerline**	**Centerline Only**	**Shoulder and Centerline**
Segment Length (miles)	944.63	282.52	2.20	1.03
Total Segment Length (miles)	1230.37			
Cost/Installation Type	$598,516	$343,092	$3,129	$2,388
Cost/Pavement Type	$941,608		$5,517	
Total Cost	**$947,126**			
Installation Year	**2010**			
Pavement Type	**Asphalt**		**Concrete**	
Installation Type	**Centerline Only**	**Shoulder and Centerline**	**Centerline Only**	**Shoulder and Centerline**
Segment Length (miles)	1272.26	288.51	15.44	4.63
Total Segment Length (miles)	1580.83			
Cost/Installation Type	$806,102	$350,368	$22,014	$10,745
Cost/Pavement Type	$1,156,470		$32,759	
Total Cost	**$1,189,229**			
Three-Year Total Cost (2008, 2009, & 2010)	**$3,357,978**			

Table 13. Summary of the Estimated Cost of MDOT's Rumble Strip Program

Pavement Type	Asphalt		Concrete	
Installation Type	Centerline Only	Shoulder and Centerline	Centerline Only	Centerline and Shoulder
Segment Length (miles)	3054.09	1132.22	17.64	9.81
Cost/Installation Type	$1,935,069	$1,374,970	$25,143	$22,795
Cost/Pavement Type	$3,310,039		$47,939	

The cost of milling rumble strips varies by the state and size of the job. Costs of the rumble strip per linear feet in different states were reviewed and tabulated as shown in Appendix II. It should be noted that it is unknown whether traffic control or other costs are included in the unit prices from other states. The unit costs of the rumble strips were found to be as low as $0.06/ft. in Alaska and as high as $10.49/ft. for asphalt pavement in Virginia. Both of these costs may be due to special circumstances and could have been influenced by the quantity of work in the project. Michigan unit costs of $0.12/ft. for asphalt pavement and $0.27/ft. for concrete pavement are comparable to other states.

While there are multiple sources of crash costs, such as the Highway Safety Manual (HSM) developed by the Federal Highway Administration (FHWA), MDOT chooses to utilize the societal costs of motor vehicle crashes published by the National Safety Council (NSC) in economic evaluations. The estimate of the safety benefits for the rumble strip program was based on the average economic cost per death and the injury severity given by the National Safety Council (2012 estimates) *(14)*. They are as follows:

Fatal Crash:	$1,410,000
Incapacitating Injury (A):	$72,700
Non-Incapacitating Evident Injury (B):	$23,400
Minor Injury (C) and Property Damage Only (PDO):	$8,900

A total of 2,488 target crashes were identified for the "Before" period as a part of the Impact of Non-Freeway Rumble Strips Phase I study *(1)*. In the "After" period, a total of 1,306 target crashes were identified. A three-year "Before" and three-year "After" study shows the average reduction of 47.5% for all target crashes (total). Target crashes identified in both the "Before" period and the "After" period involve single vehicle run-off-the-road-left, head-on and opposite-direction sideswipe collisions, and are free from the crashes that involve snowy/icy pavement. Table 14 shows the estimated total benefit based on the crash and severity effectiveness data.

Table 14. Estimated Benefit

WORST INJURY IN CRASH	THREE-YEAR TARGET CRASH FREQUENCY		PERCENT REDUCTION IN TARGET CRASHES	COST OF UNIT CRASHES	ESTIMATED BENEFIT
	"BEFORE" PERIOD	"AFTER" PERIOD			
Fatal	83	40	51.81%	$1,410,000	$60,630,000
A	237	139	43.35%	$72,700	$7,124,600
B	353	177	49.86%	$23,400	$4,118,400
C	381	206	45.93%	$8,900	$1,557,500
PDO	1,434	744	48.12%	$8,900	$6,141,000
Total	**2,488**	**1,306**	**47.51%**		**$79,571,500**

Maintenance Cost

According to the MDOT "Capital Preventive Maintenance Manual" *(15)*, maintenance of centerline rumble strips require the grooves to be milled again after any preventive maintenance is applied on the deteriorated pavement. The following are the preventive maintenance treatments that may require centerline rumble strip to be milled again, per the manual.

<u>Flexible and Composite Pavement Treatments</u>

- Non-Structural HMA Overlay
- Surface Milling with Non-Structural HMA Overlay
- Chip Seals
- Paver Placed Surface Seal
- Micro-Surfacing

It should be noted that generally a single coat of chip seal does not require the existing centerline rumble strip to be re-milled.

Rigid Pavement Treatments

- Full Depth Concrete Pavement Repair

Preventive maintenance of a road segment generally depends upon the existing condition of the pavement that is defined by the Distress Indices (DI) and the Remaining Service Life (RSL). However, it is desirable to assume a probable time interval in between two consecutive preventive maintenance treatments.

The MDOT manual suggests the types of preventive maintenance treatments and the corresponding recommended ages of the road segment when they should be applied. It also suggests that a newly constructed pavement surface requires preventive maintenance as early as 10 years after the construction. Therefore, it is reasonable to assume that a road segment receives at least one complete maintenance treatment for its life of 20 years.

The estimated cost of a single maintenance treatment related to the construction cost of the centerline rumble strip, for the entire 4,214 miles of road segments is $3,357,978, as shown in Table 13 (page 27). The system-wide installation of centerline rumble strips in Michigan started in 2008 and was completed in 2010. A life cycle period of a newly constructed or maintained asphalt pavement is considered 20 years [Pavement Design and Selection Manual *(16)*]. A starting point from the year 2010 that spans up to the year 2030 is considered for the economic analysis.

The initial construction cost of the 4,214 miles of centerline rumble strips is estimated at $3,357,978, as shown in Table 13 (page 27). A newly constructed pavement section will receive its complete maintenance treatment at an interval of 10 years and the maintenance cost will be the same as the initial installation cost. The initial installation and one cycle of maintenance cost are considered in the program cost. Pavement segments will receive another cycle of maintenance at the age of 20 years that will be considered in the next life cycle period for the pavements and will not be included in this benefit-cost analysis.

The vestcharge (discount) is a rate of return used in capital budgeting to measure and compare the profitability of investments. It is generally lower for the infrastructure-related projects as compared to interest rates often used to perform an economic analysis of products or systems in traditional business decisions.

Assumption of an appropriate vestcharge rate or discount rate impacts the accrued benefits and costs significantly. Therefore, generating a range of benefits-cost ratios for a range of discount/vestcharge rates is desirable, rather than assuming a single discount rate.

A sensitivity analysis has been performed using a series of vestcharge/discount rates in estimating the annual maintenance cost and the benefit to cost ratio. The sensitivity curve, thus obtained, can be used to determine the corresponding benefit to cost ratio for different vestcharge rates.

Assuming a vestcharge rate of 2% is used to estimate annualized total cost

Present Worth of Total Cost = Total initial cost + Present worth of maintenance costs
= $3,357,978 + 1.2190 X $3,357,978
= $7,451,353.18

Equivalent Uniform Annual Cost (EUAC) = Annualized present worth of total cost
= 0.06115 X $7,451,353.18
= $455,700.17

The total 3-year benefit attributed to the centerline rumble strip program is estimated as $79,571,500 for the three years of "After" period, as shown in Table 14 (page 28). In order to estimate the Equivalent Uniform Annual Benefit (EUAB), the total benefit would have to be projected over the 20-year life cycle period and distributed annually using the appropriate vestcharge rate. However, for simplicity, the annual benefit is estimated taking an average of the total benefit for three years of "After" period. Also, it is assumed that the crash and injury costs will remain constant for the analysis period in the absence of any data regarding the escalation of future economic crash and injury cost over time.

Estimated Uniform Annual Benefit = $\frac{\$79{,}571{,}500}{3}$ = \$26,523,833

Estimated Benefit to Cost Ratio = $\frac{EUAB}{EUAC} = \frac{\$26{,}523{,}833}{\$455{,}700}$ = 58.2

Similarly, Figure 8 shows the changes in the benefit to cost ratio as a function of various vestcharge rates.

The results of the sensitivity analysis allow determination of the appropriate benefit-cost ratios for a selected vestcharge or discount rate. Vestcharge or discount rates for highway infrastructure, such as rumble strips, are appropriate rather than using normal "interest rates" as discussed earlier. Functionally both terms represent an opportunity to invest money in public infrastructure projects.

This economic analysis indicates that the implementation of CLRS on two-lane highways will yield a benefit-cost ratio of approximately 58 for a 2% discount rate, to approximately 18 for a 10% discount rate.

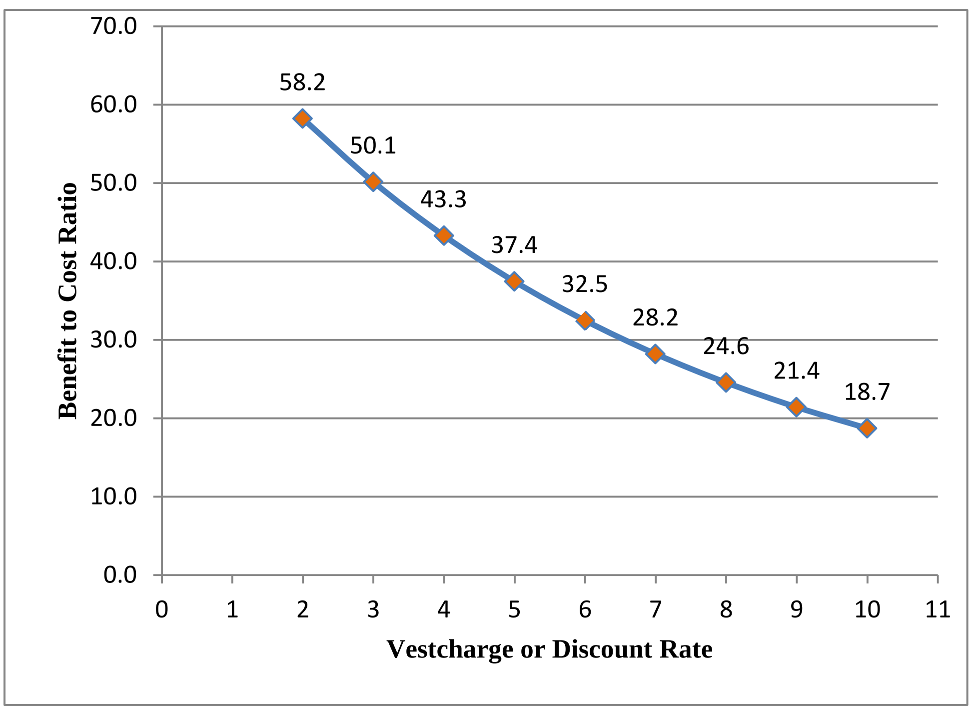


Figure 8. Benefit to Cost Ratios for Various Rates

VII. CENTERLINE RUMBLE STRIP SURVEY

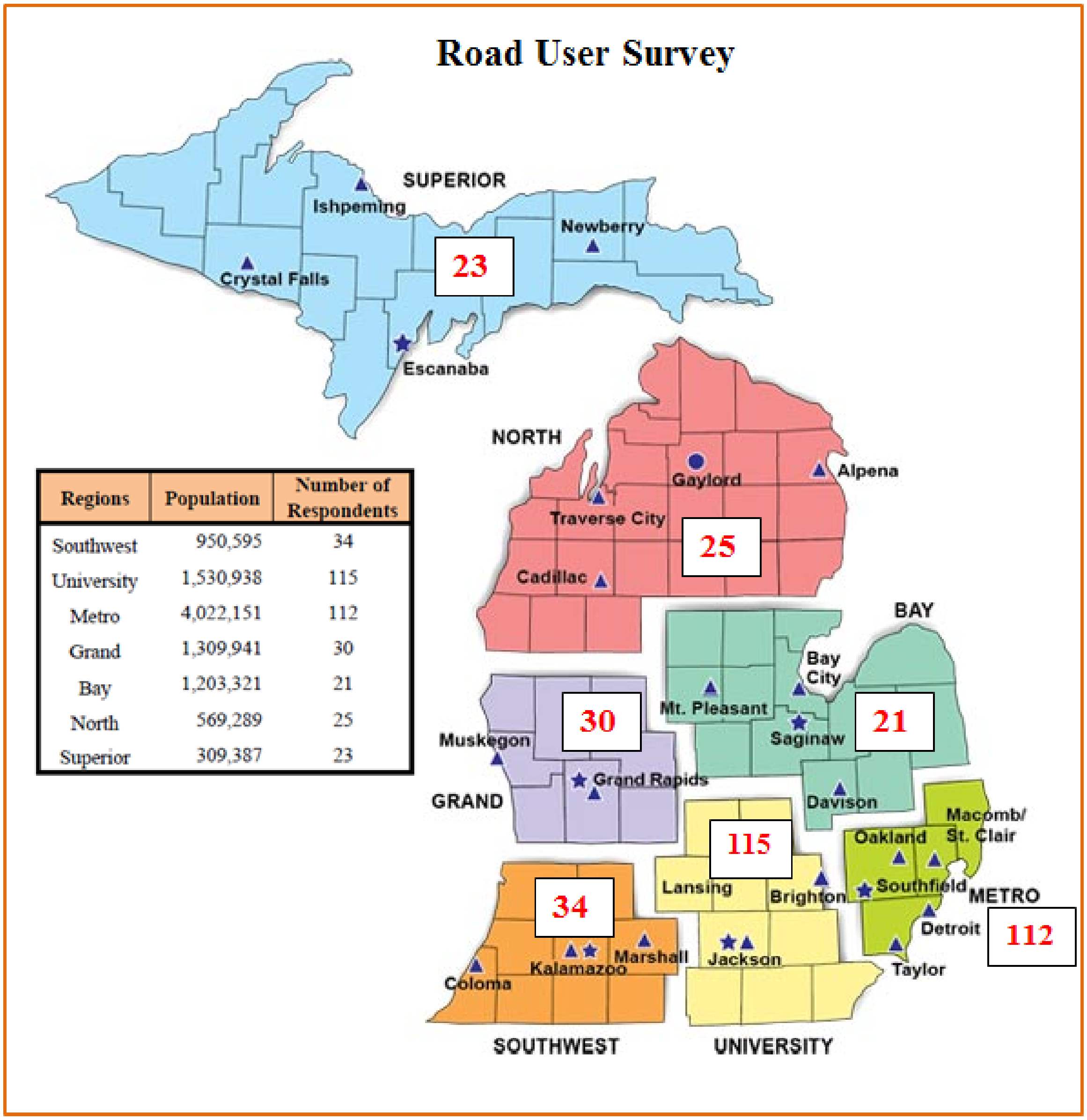
Public Impression Road User Survey

As part of MDOT's rumble strip effectiveness evaluation study, a road user impression survey was performed to help gain valuable insight of the public's perception on the use of centerline rumble strips on two-lane highways (see Appendix III for the survey). The online survey was available to all road users through MDOT's webpage and social media sites. Responses to the survey were random. Road users who were more opinionated about CLRS may have been more inclined to respond.

A total of 380 completed survey responses were received, with 360 of them listing their county of residence. The remaining 20 respondents either did not include it, or were from out of state. The completed survey respondents, by MDOT region, are shown in Figure 9. The population data by MDOT regions was extracted from the 2013 census estimates and have also been included.

The age group ranged from less than 20 years old to greater than or equal to 61 years. Thirty-six (36) percent of respondents were female and 64 percent were male. Most respondents answered that they have encountered centerline rumble strip segment(s) in their normal driving, with 31 percent noting it was due to a passing maneuver, 19 percent due to avoiding a vehicle, animal, or other object in the roadway, 16 percent due to being distracted, 14 percent due to the weather, 13 percent due to visibility issues, and 7 percent being tired.

In terms of agreeing with centerline rumble strips improving safety on Michigan two-lane highways, 79 percent of the respondents either strongly agreed or agreed, while only 4.4 percent either strongly disagreed or disagreed, while 16.7 percent remained uncertain. Nearly all of the respondents believe centerline rumble strips help keep motorists in their lane when distracted or tired; however, most responded that centerline rumble strips do not deter them from passing a slower moving vehicle.



Regions	Population	Number of Respondents
Southwest	950,595	34
University	1,530,938	115
Metro	4,022,151	112
Grand	1,309,941	30
Bay	1,203,321	21
North	569,289	25
Superior	309,387	23

Figure 9. Respondents' Residence Location

Thirty-two (32) percent of the respondents noted that they live or work on a route where centerline rumble strips have been installed, with most believing the safety benefits outweigh the noise that they create. Seventy-two (72) percent of the survey respondents had experience driving on roads with centerline rumble strips under bad weather conditions, with over 3/4 of them agreeing that the rumble strips were helpful in their driving. The majority of respondents would recommend centerline rumble strips to be installed on more Michigan roadways.

MDOT Pavement Personnel Survey

A survey of MDOT pavement design and maintenance personnel including field engineers was also conducted to capture their experiences and impressions regarding pavement performance, short term and long term, that include CLRS. The survey form is included in Appendix IV. The intent of this survey was to identify and consider any opinions regarding the impact of CLRS on pavement performance.

Feedback was received from only 15 MDOT personnel. The majority of respondents either strongly agree or agree that the installation of centerline rumble strips on MDOT two-lane highways improves safety. A little over half of respondents believe centerline rumble strips damage or weaken the pavement in a short time period (1 to 3 years), while most believe centerline rumble strips damage or weaken the pavement in a long period of time (greater than 3 years).

When asked what type of potential pavement distresses could be related to centerline rumble strips, respondents replied with premature surface failure, longitudinal cracks, pot holes, HMA spalling, separation, and unraveling. Sixty-one (61) percent of the respondents noted that their design or maintenance strategy changes for a road with centerline rumble strips, including maintenance personnel having to spend more time fixing and repairing the centerline.

However, there was no discernible uniformity amongst the professionals who responded to the survey, indicating that the limited responses may have been based on their personal experience and opinion, rather than objective data.

VIII. STUDY CONCLUSIONS

The Phase II study primarily involved collection of “After” data for MDOT two-lane rural highways’ rumble strip installation program, evaluation of its safety performance and an assessment of public impression regarding the use of CLRS as a safety measure.

A comprehensive evaluation of safety performances of CLRS on two-lane rural highways resulted in the following conclusions:

- Total target traffic crashes reduced by 47% after system-wide installation of CLRS on rural two-lane high-speed highways.
- Fatal and "A" injury crashes reduced by 51% and 41%, respectively.
- "B" and "C" type injury crashes also reduced by 49% and 45%, respectively.
- Property Damage Only "PDO" crashes decreased by 48%.
- Head-on, sideswipe opposite direction and run-of-the-road crashes went down 50%, 55%, and 46%, respectively, and the reductions were statistically significant.
- Passing-related crashes reduced by 47%. This indicates that the drivers may have been a bit more cautious in selecting gaps in opposing traffic for a passing attempt.
- Target crashes excluded snowy and icy pavement to eliminate the effect of a snow fall difference over a longer time period. A study of annual average precipitation comparison between "Before" and "After" periods showed only nominal changes. The comparison of crashes with "wet pavement" demonstrated a 53% reduction in target crashes, and was statistically significant. Such a reduction under challenging environmental conditions should be noted.
- The analysis of crashes involving an "impaired driver" as a contributing factor also indicated a reduction of 35%. The action and behavior of impaired drivers are anecdotally similar to that of a distracted or drowsy driver; therefore, it is expected that encroaching over CLRS may alert drivers to take crash avoidance actions.

A road user survey indicated a strong support for the use of CLRS as a safety measure, even when the presence of CLRS may cause occasional inconvenience and driving discomfort for the respondents. While the survey was voluntary and did not include a statistically robust sample, respondents' comments indicated that the majority favored CLRS as a safety treatment on two-lane high speed highways.

Future research should include the installation and evaluation of the effect of rumble strips on slightly lower speed two-lane highways. Also, future research may focus on the use of CLRS on four-lane highways and the determination of their effectiveness.

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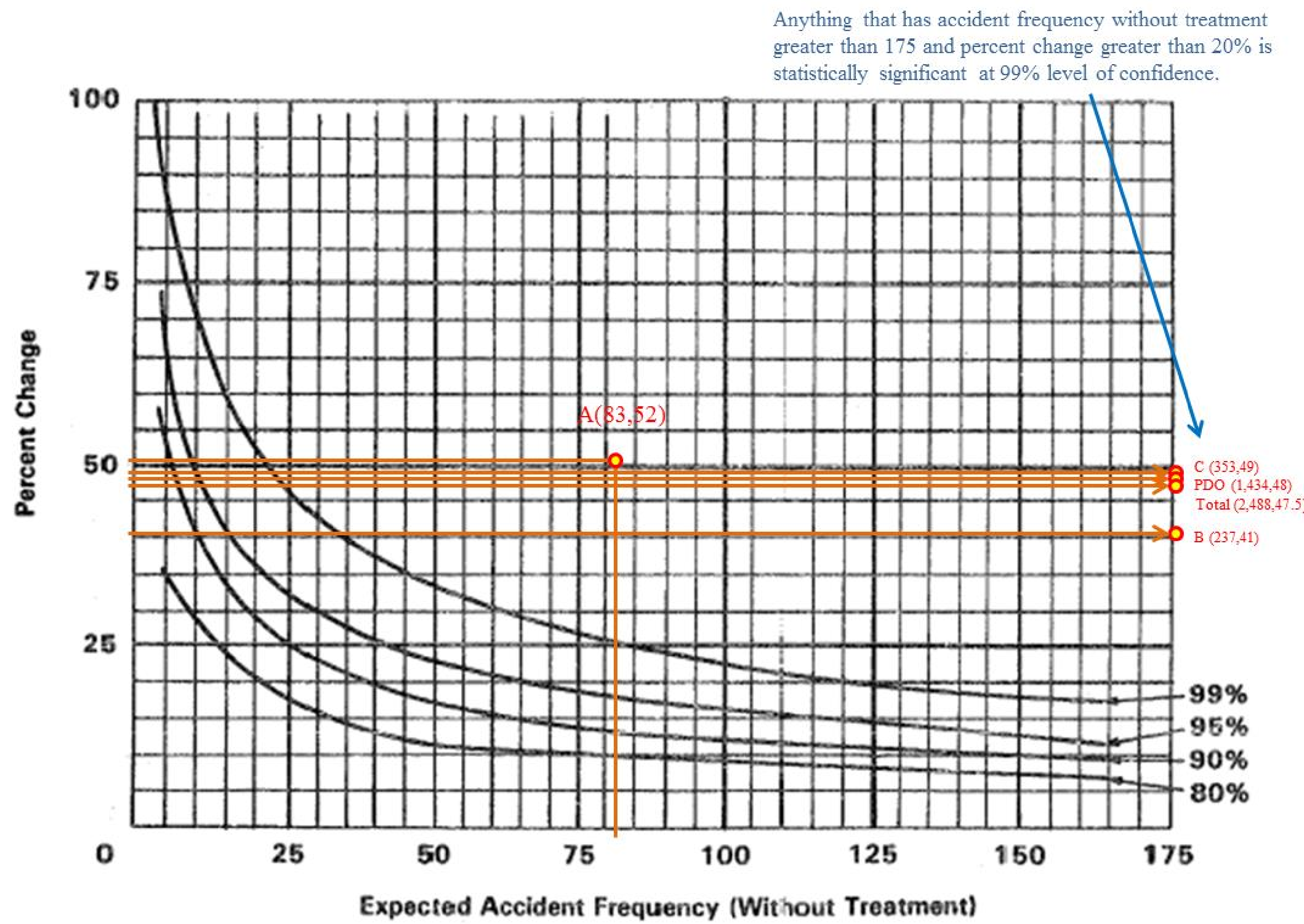
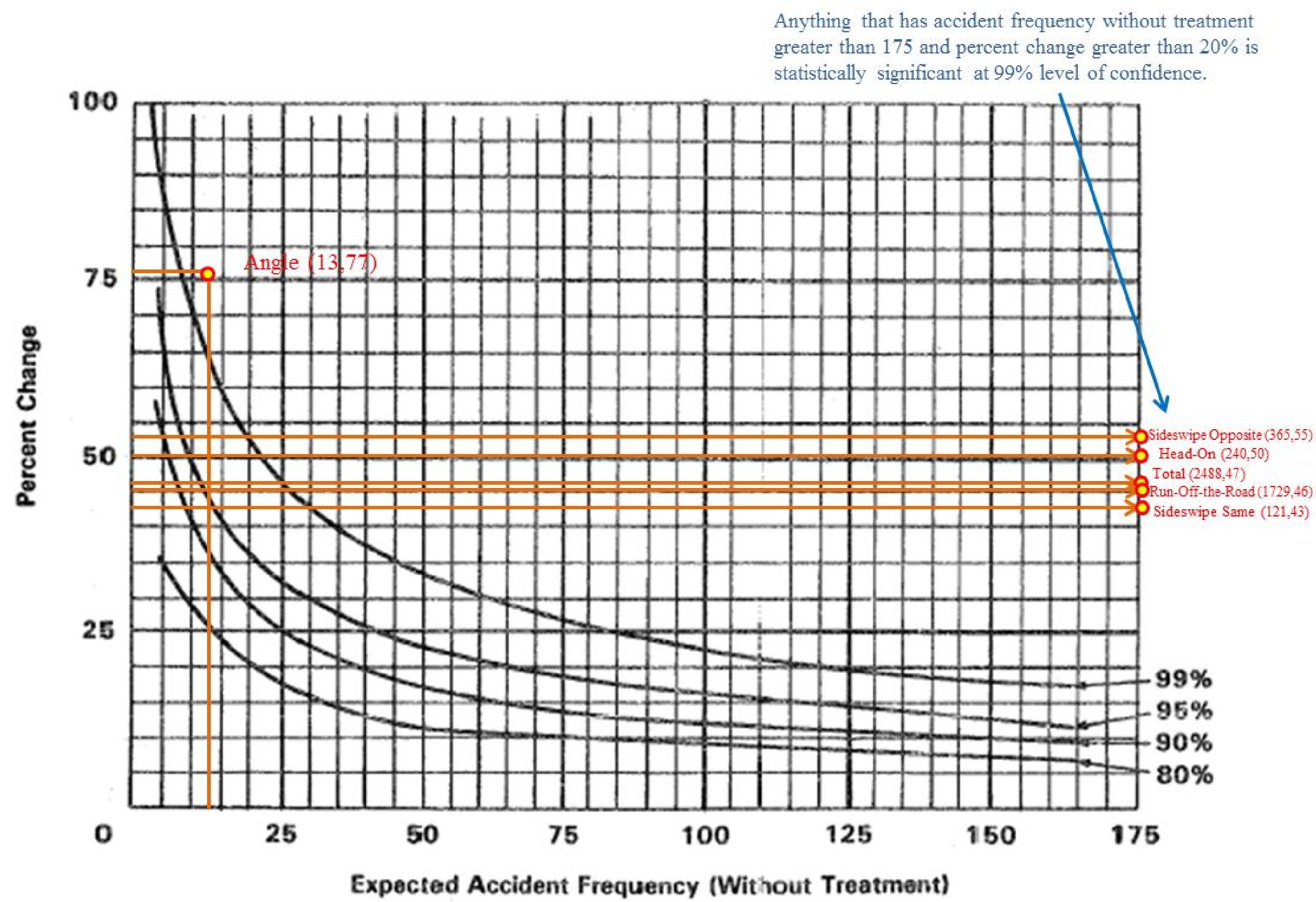
APPENDIX I – LEVEL OF SIGNIFICANCE FOR CRASH REDUCTION (POISSON'S DISTRIBUTION)



Note:

- X co-ordinate represent accident frequency without treatment
- Y co-ordinate represent percent change in the crash type

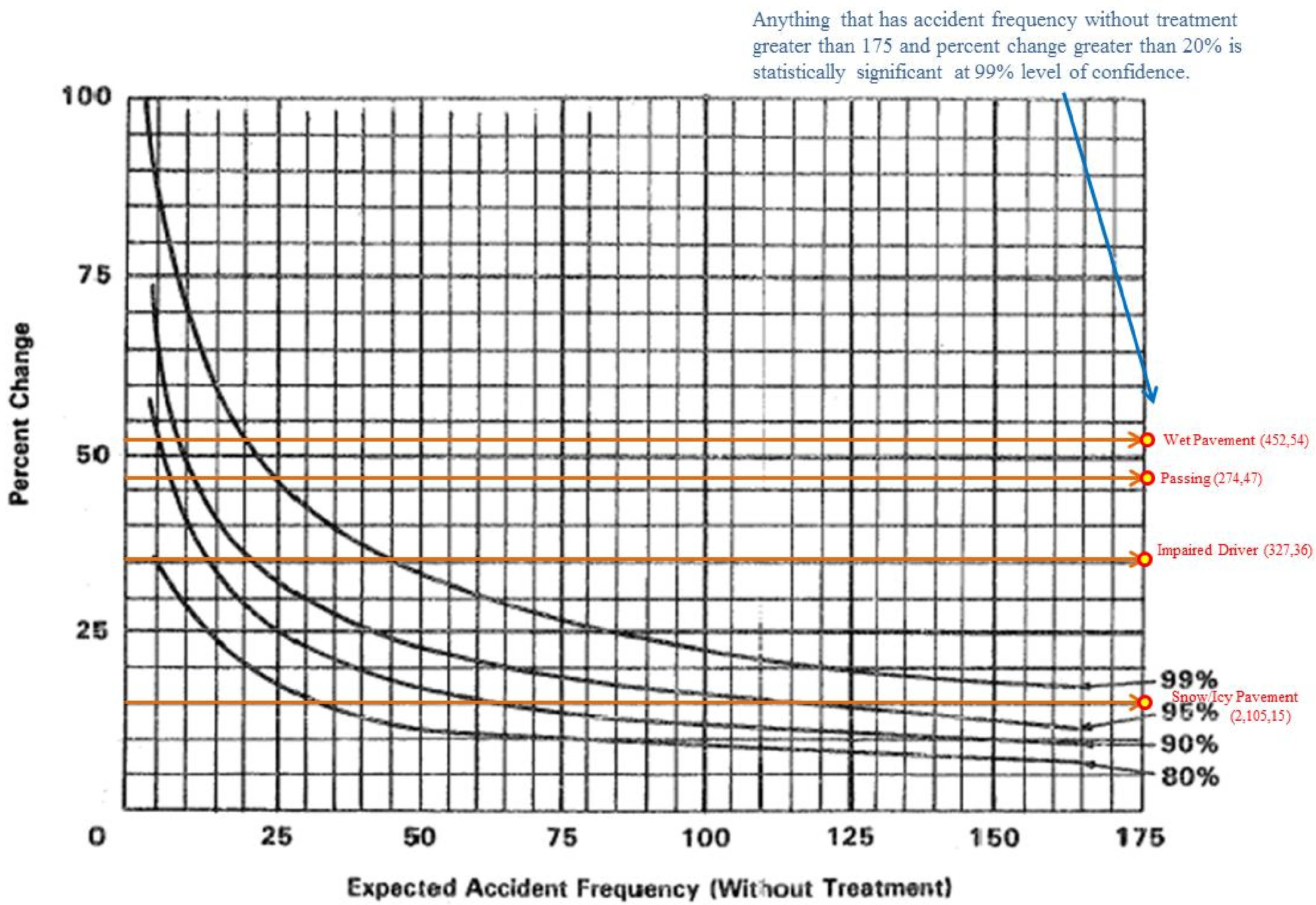
Level of Significance Verification of Table 8



Note:

- X co-ordinate represent accident frequency without treatment
- Y co-ordinate represent percent change in the crash type

Level of Significance Verification of Table 9



Note:
- X co-ordinate represent accident frequency without treatment
- Y co-ordinate represent percent change in the crash type

Level of Significance Verification of Table 10

APPENDIX II – RUMBLE STRIP COSTS AS REPORTED BY VARIOUS STATES

STATE	RUMBLE STRIP DESCRIPTION/SPECIFICATION	COST (DOLLARS/ LINEAR FEET)
Alabama	Rumble Strips (6" Wide)	$0.08
Alaska	Milled Rumble Strips (Unspecified)	$0.06
Arizona	Centerline Rumble Strips (8" Wide)	$0.20
Arkansas	Centerline Rumble Strips (Asphalt)	$0.50
	Shoulder Rumble Strips (Asphalt)	$0.16
	Shoulder Rumble Strips (Concrete)	$0.19
California	Rumble Strips (Unspecified)	$0.30
Colorado	Rumble Strips (Unspecified)	$0.19
Connecticut	Rumble Strips (Automated)	$0.15
	Rumble Strips (Manual)	$0.15
	Centerline Rumble Strips	$0.35
Delaware	Rumble Strips (Unspecified)	$0.24
Georgia	Rumble Strips (Asphalt)	$0.13
Hawaii	Rumble Strips (Unspecified)	$3.00
Idaho	Rumble Strips (Unspecified)	$0.17
Iowa	Milled Shoulder Rumble Strips (Concrete)	$0.08 to 0.20
	Milled Centerline Rumble Strips (Concrete)	$0.09 to 0.34
Kansas	Milled Shoulder Rumble Strips (Asphalt)	$0.08
	Milled Centerline Rumble Strips (Asphalt)	$0.08
Maine	Centerline and Edgeline Rumble Strips	$0.45
Maryland	Centerline Rumble Strips	$0.14 to 0.41
Michigan	Centerline Rumble Strips (Asphalt) – 2003 Specification	$0.12
	Centerline Rumble Strips (Concrete) – 2003 Specification	$0.27
	Centerline Rumble Strips (Asphalt) – 2012 Specification	$0.24
	Centerline Rumble Strips (Concrete) – 2012 Specification	$0.45
	Shoulder Rumble Strips (Asphalt)	$0.11
	Shoulder Rumble Strips (Concrete)	$0.17
Minnesota	Edgeline Rumble Strips	$0.57

STATE	RUMBLE STRIP DESCRIPTION/SPECIFICATION	COST (DOLLARS/ LINEAR FEET)
Missouri	Edgeline Rumble Strips	$0.38
	Centerline Rumble Strips	$0.55
Montana	Shoulder Rumble Strips (Non-freeway)	$0.09
	Shoulder Rumble Strips (Freeway)	$0.35
Nebraska	Rumble Strips (Unspecified)	$0.08
Nevada	Rumble Strips (Unspecified)	$0.13
New Hampshire	Rumble Strips (16" wide)	$0.16
New Jersey	Rumble Strips (Unspecified)	$0.20
New Mexico	Rumble Strips (Unspecified)	$0.09 to 0.25
New York	Rumble Strips (Unspecified)	$0.30
North Carolina	Milled Rumble Strips (Unspecified)	$0.15 to 7.40
Ohio	Rumble Strips (Asphalt)	$0.80
Oregon	Rumble Strips (Unspecified)	$0.13 to 0.17
South Carolina	Rumble Strips (Asphalt)	$0.07 to 0.28
South Dakota	Rumble Strips (Asphalt)	$0.30
Tennessee	Rumble Strips (4" Wide)	$0.80
	Rumble Strip (8" Wide)	$0.80
	Shoulder Rumble Strips (Concrete)	$3.50
Texas	Centerline Rumble Strips	$1.50
Utah	Longitudinal Rumble Strips	$0.19 to 0.20
Vermont	Milled Rumble Strips (Unspecified)	$0.15 to 0.50
Virginia	Rumble Strips (Asphalt)	$0.10 to 10.49
Washington	Centerline Rumble Strips	$0.32
	Shoulder Rumble Strips	$0.13
West Virginia	Edgeline Rumble Strips (Asphalt)	$0.20
	Centerline Rumble Strips (Asphalt)	$1.00
	Rumble Strips (ADAB)	$0.45

APPENDIX III – MICHIGAN ROAD USER IMPRESSION SURVEY

Wayne State University Transportation Research Group
Evaluation of Non-Freeway Rumble Strips – Phase II
Michigan Road Users Impression Survey
http://www.surveymonkey.com/s/rumblestriproaduser

The purpose of this survey is to collect information from Michigan road users regarding the performance of centerline rumble strips on Michigan two-lane highways. Centerline rumble strips are a pattern of depressions installed on the centerline of two-lane highways to alert distracted or drowsy drivers that they are crossing the centerline. Many states have reported reductions in head-on and related crashes after installation of centerline rumble strips. This survey can be completed online at: http://www.surveymonkey.com/s/rumblestriproaduser Your participation in this effort and your responses to these survey questions would be greatly appreciated. Thank you for your participation.

1. Age:
   □ Less than 20 □ 21-30 □ 31-40 □ 41-50 □ 51-60 □ 61 or Greater

   Gender:

   □ Male □ Female

   County of Residence: ______________________________

2. Have you ever driven over a centerline rumble strip? (If your answer is "No," proceed to Question 4)

   □ Yes □ No

3. If you responded "Yes" to Question 2, what is the reason you have driven over a centerline rumble strip? (Check all that apply):

   □ Distracted
   □ Tired
   □ Passing
   □ Avoid vehicle, animal, or other object in roadway
   □ Weather
   □ Darkness/visibility issues
   □ Other, please specify:

4. To what extent do you agree with the following statement?

   Centerline rumble strips have improved safety on Michigan two-lane highways.

   □ Strongly agree □ Agree □ Uncertain □ Disagree □ Strongly disagree

5. Do you believe that centerline rumble strips help keep motorists in their lane when distracted/tired?

   □ Yes □ No

6. Does the presence of centerline rumble strips ever deter you from passing a slower moving vehicle?

   □ Yes □ No

7. Do you live or work on a route where centerline rumble strips have been installed?

   □ Yes □ No

   If yes, do you think the safety benefit outweighs the noise created?

   □ Yes □ No

8. Have you had any experience driving on roads with centerline rumble strips during bad weather conditions?

   □ Yes □ No

   If yes, were the rumble strips helpful to you in your driving task?

   □ Yes □ No

9. Based on your personal experience, would you recommend centerline rumble strips be installed on more Michigan roadways?

   □ Yes □ No

10. Please provide any other comments you may have regarding the use of centerline rumble strips.

____

____

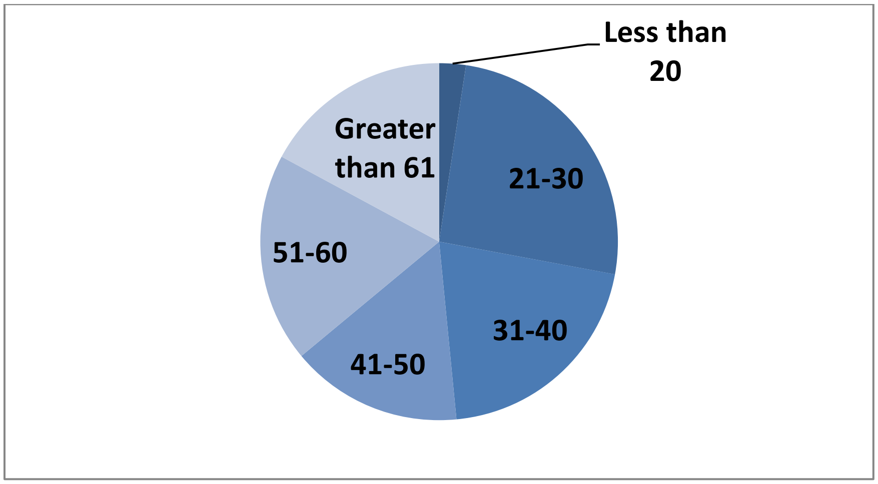
____

Completed surveys can be e-mailed, faxed, or mailed to:

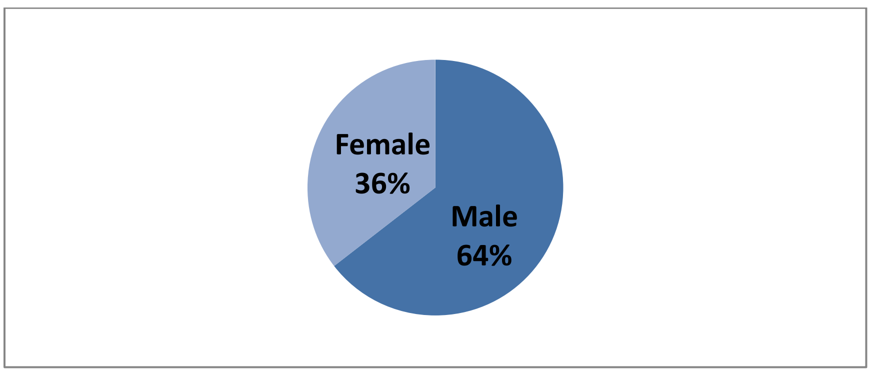
Tapan K. Datta, Ph.D., P.E.Professor
Fax Number: (313)-577-8126
tdatta@eng.wayne.edu
5050 Anthony Wayne Drive, EDC, Room #0504
Detroit, MI 48202-3902

Michigan Road Users Impression Survey Results

1. Age:



Gender:



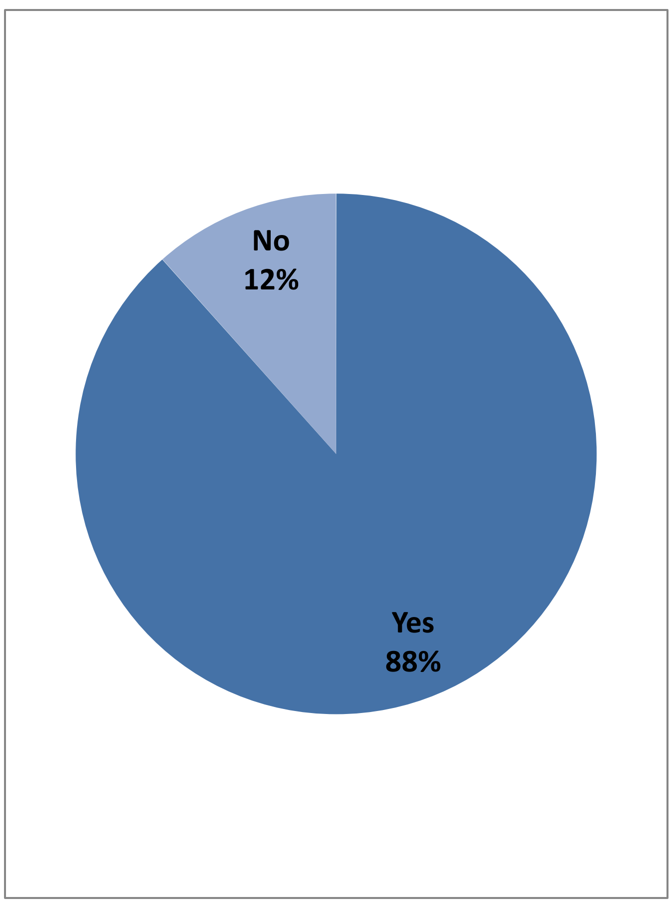
County of Residence:

Region	County	Number of Respondents
Southwest	Allegan	2
	Barry	2
	Berrien	5
	Calhoun	3
	Kalamazoo	18
	St. Joseph	2
	Van Buren	2
	Total	34

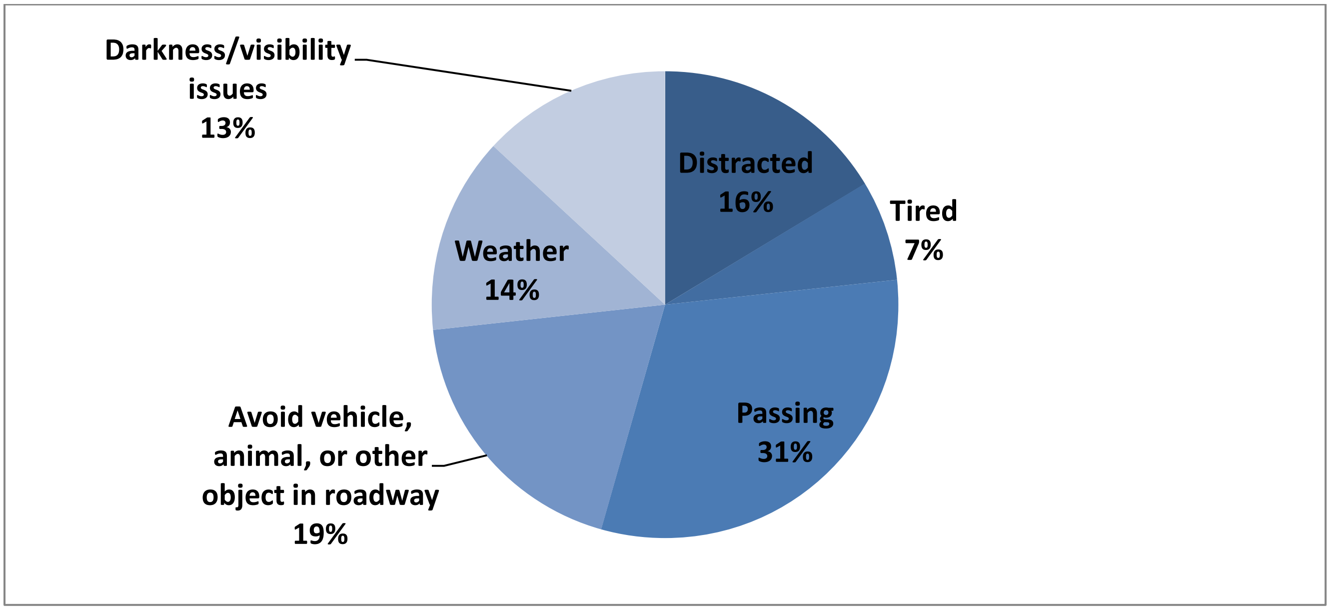
Region	County	Number of Respondents
University	Clinton	7
	Eaton	19
	Hillsdale	5
	Ingham	31
	Jackson	13
	Lenawee	1
	Livingston	14
	Monroe	1
	Okemos	1
	Shiawassee	7
	Washtenaw	16
	Total	115
Grand	Grand Rapids	1
	Ionia	2
	Kent	16
	Mecosta	1
	Montcalm	1
	Muskegon	3
	Oceana	1
	Ottawa	5
	Total	30
Bay	Bay	1
	Genesee	2
	Gratiot	2
	Isabella	4
	Midland	3
	Saginaw	4
	Sanilac	3
	Tuscola	2
	Total	21
Metro	Macomb	31
	Oakland	55
	St. Clair	1
	Wayne	24
	Total	112
North	Alpena	2
	Antrim	1
	Benzie	3
	Emmet	3
	Grand traverse	9
	Kalkaska	2
	Leelanau	2
	Mason	1
	Otsego	1
	Wexford	1
	Total	25

Region	County	Number of Respondents
Superior	Alger	1
	Chippewa	2
	Delta	1
	Gogebic	1
	Hancock	1
	Houghton	8
	Iron	1
	Marquette	6
	Menominee	1
	Schoolcraft	1
	Total	23
Out of State	Ascension	1
	Benguet	1
	Minnesota	1
	Out of State	1
	Palm Beach	1
	United States	15
	Total	**20**

2. Have you ever driven over a centerline rumble strip? (If your answer is "No," proceed to Question 4)



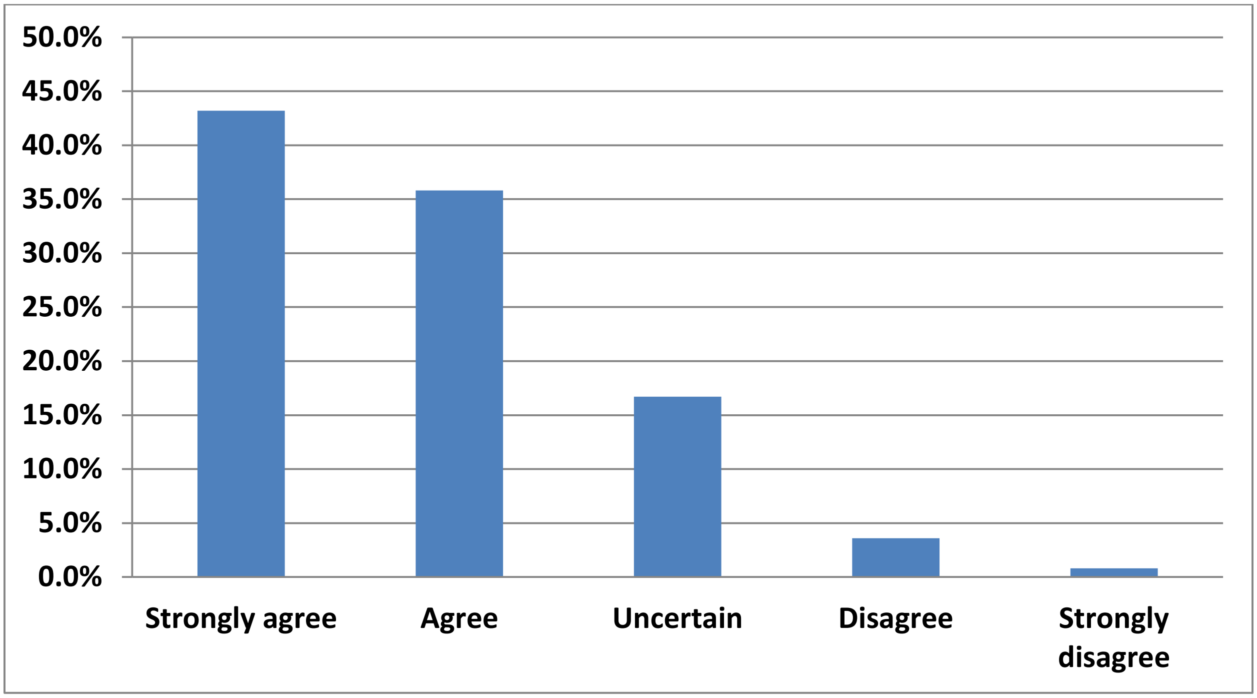
3. If you responded “Yes” to Question 2, what is the reason you have driven over a centerline rumble strip? (Check all that apply):



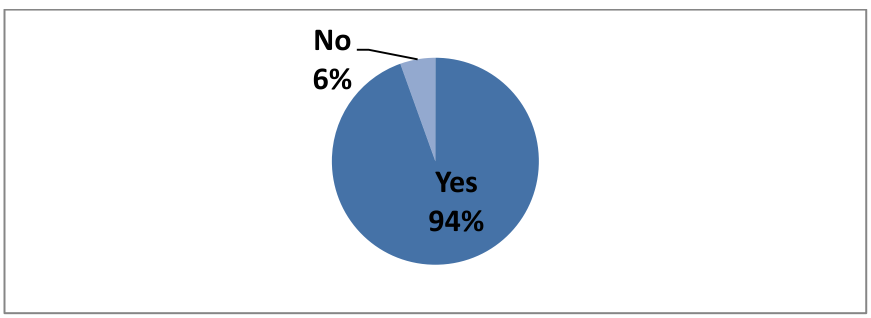
Other, please specify:

- Curious as to level of sound caused by driving over it
- Give space to vehicle, bicycle, etc. on shoulder
- Curiosity
- Poor lane following
- Wanted to get ride feel
- Weather - partially snow covered
- Snow - cover makes these a problem
- Can't recall specifically why I drove over, just know I did
- Turn into a driveway
- Narrow lanes
- Due to snow cover on the road I could not see the lanes
- Also to see how they sound and feel
- Going too fast around curve
- Going around curve
- So others in my vehicle can hear the sound as we talk about them
- Can't avoid them at most driveways
- Wanted to see what they sounded like
- Natural curve of the road
- Making a left turn down my street.
- Cop pulled somebody over or Tractors or wide loads
- Cross wind
- To see what they sound like
- To see how effective it was

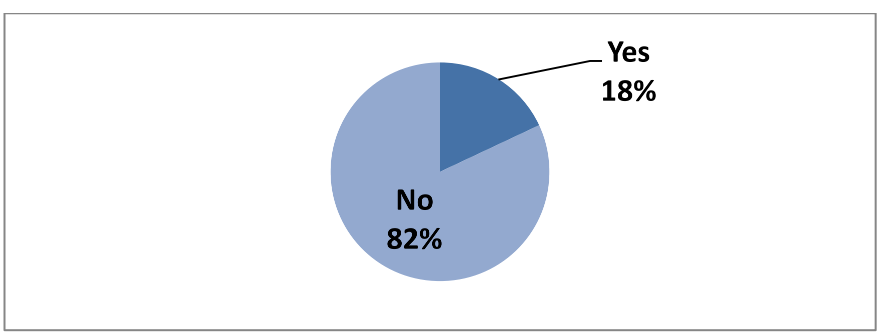
4. To what extent do you agree with the following statement? "Centerline rumble strips have improved safety on Michigan two-lane highways."



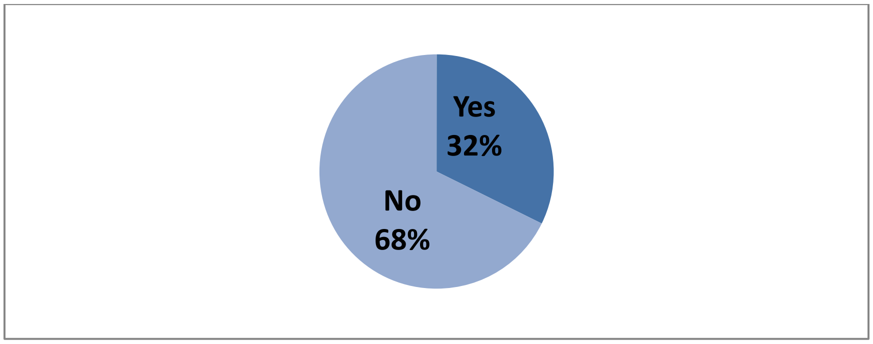
5. Do you believe that centerline rumble strips help keep motorists in their lane when distracted/tired?



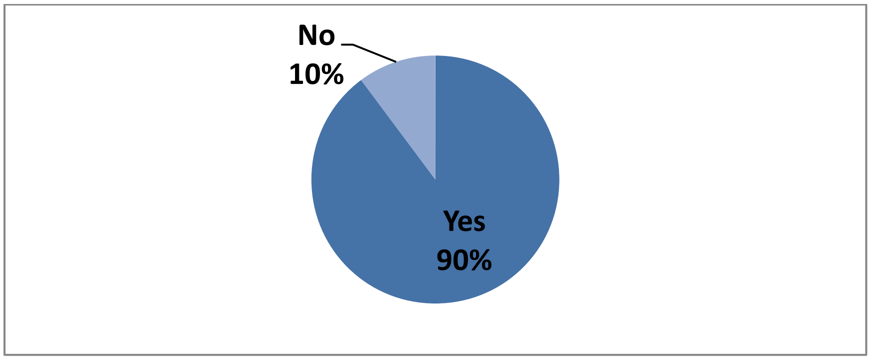
6. Does the presence of centerline rumble strips ever deter you from passing a slower moving vehicle?



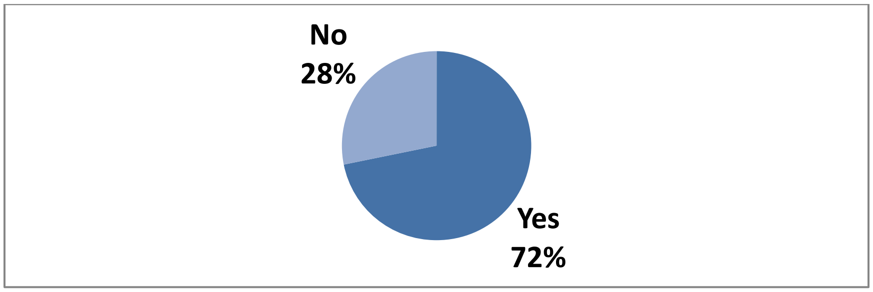
7. Do you live or work on a route where centerline rumble strips have been installed?



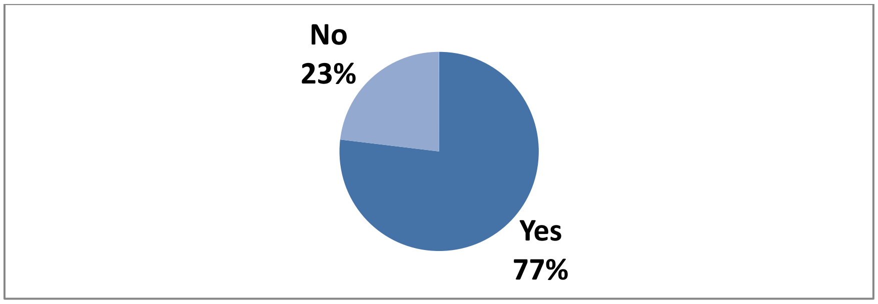
If yes, do you think the safety benefit outweighs the noise created?



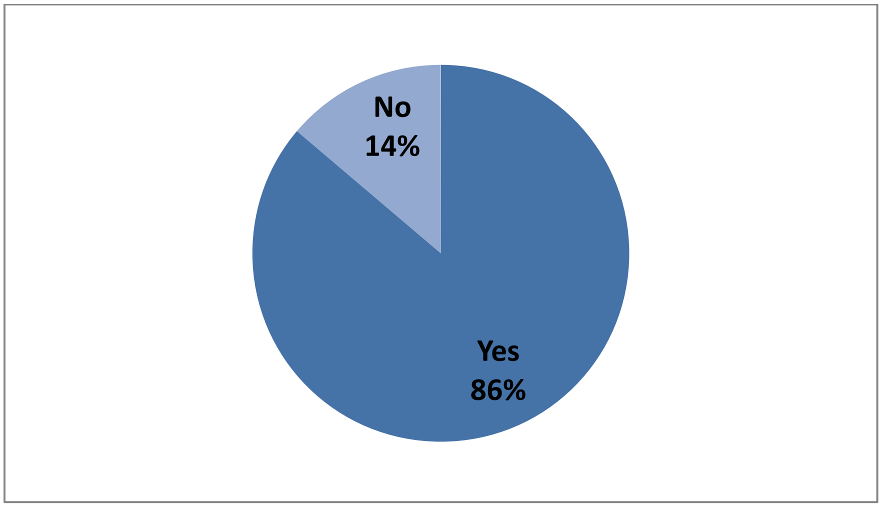
8. Have you had any experience driving on roads with centerline rumble strips during bad weather conditions?



If yes, were the rumble strips helpful to you in your driving task?



9. Based on your personal experience, would you recommend centerline rumble strips be installed on more Michigan roadways?



10. Please provide any other comments you may have regarding the use of centerline rumble strips.

- They were installed on a roadway in our community and I at first had concerns about their noise levels; however, in the end my concerns were mostly unfounded. PS - On question 5 I only wanted to enter an answer for other, however, the survey would not continue if I didn't select a box so I selected one in order to finish survey.
- I think that they are good in areas with a high head-on crash rate, but should not be installed on every two lane road.
- I still have yet to encounter them. I think they are a good idea.
- My elderly Father fell asleep with my Mother in the car driving on a road with centerline rumble strips. I believe that the strips saved both of their lives, and possibly others in on-coming cars.
- They surely lead to more pot holes at the centerline of the road. I see it every day.
- I really find the rumble strips useful during bad weather. I wish there were more around here because people have a hard time staying on their side of the road.
- I can’t really think of anywhere where they actually have these, but the few I remember driving over were pretty annoying.
- I would recommend centerline rumble strips for mainly highways, don't see the need for smaller roads. May be useful at night for poorly lighted roads.
- No rumble strips on residential roads.
- They are great to have in a state like ours.
- Stop using the limits of a city as a point to stop the rumble strips and instead look at the surrounding area and development (or lack thereof) to determine where is the appropriate stop to stop installing them.

- Potholes should be the first and only priority.
- Try building a reliable road before deciding what to put on top of it. Construction is a plague in Michigan's legacy and it's about time my tax money is put into a properly engineered road surface instead of stick on reflectors.
- Centerline rumble strips are awesome for driving in the UP in the winter when the roads are snow covered and you can't see where the lanes are.
- Sounds like a good idea.
- I think any extra warning system that can help reduce accidents--especially head-on collisions--that is so minimal as stamping concrete, I see no reason why this should not be implemented. I am sure we will incur greater taxes for our roadways, but I think the amount of money we put towards roads in Michigan is laughable anyway. I wish these rumble strips could be implemented right along with new funding and road paving strategies for Michigan into the future. The fact that funding is so tight for our roadways, I cannot see a regulation such as this passing now, but I think centerline rumble strips would be a great addition to Michigan roadways.
- Centerline and curb rumble strips are an effective warning when your vehicle wanders within the lane.
- Obviously the improved safety is the benefit of rumble strips but a downside is the maintenance of them. Over time they wear and become less pronounced. In addition, they may hold water or snow/ice and may in some cases obscure the pavement markings if the marking goes through them. Also, if they hold water, does it negatively affect the deterioration of the roadway surface?
- How much do they cost and can they be installed during other road maintenance?
- It would also be helpful if counties would do more frequent painting of stripes down the center and fog lines on the edges. Really need these at night in rural areas.
- Helpful but annoying. I guess that's why they are there. I think they do improve safety.
- Rather than investing in centerline rumble strips, we need to invest in public transit !!!
- Fix all the potholes and terrible roadways before spending any more money on rumble strips.
- Useful on curves to keep you in your lane.
- In the winter, snow builds up in the rumble strips and sometimes, depending on weather (windy or large snow events) the snow build-up seems to creep out from the center in the rumble strip pattern into the through lanes. In northern MI, I have noticed that road with rumble strips tend to deteriorate quicker at the center where the rumble strips are located.
- Centerline rumble strips are helpful at night when you are not sure if you have drifted into the center of the road.
- Centerline rumble strips are great. They seem like a low cost safety improvement yielding a high B/C ratio. I'm not sure if they would affect

bicyclists on the shoulder or not by influencing motorist's passing behaviors? Maybe something that could be researched further down the line. Also, with all of the texting and driving going on, they may save a life or two by preventing drifters into oncoming traffic.

- Have heard from others who they have helped keep them on the road during bad weather, or when tired.
- Rumble strips collect water and debris. They can deteriorate quickly and are a nuisance from the debris hazard. I think they are better suited for shoulders.
- They work because when you become distracted or tired, as soon as you hit the rumble strip, you immediately become focused on the road.
- I drive 24 miles each way to work. During the winter months I am on the road long before daylight, many days with snow covered roads and low visibility. The strips are ideal in helping to distinguish lanes. Would like to see them on the shoulders as well!
- Often in the UP these strips are snow covered in winter--so cannot always navigate to perfect lane alignment. Great idea for lower Michigan--low frequent road snow cover. Driving on these a lot in snow actually more dangerous--my thought. Noisy too.
- I think they're great!
- I truly appreciated the strips this past Michigan winter driving on snow-covered roads when the pavement markings were not visible but the rumbles kept me in my lane.
- Very helpful, especially in bad weather, tired, distracted. Thank you for installing those. I had survived once in bad weather along with night driving with bad visibility.
- As with any other costly road improvement, it seems a study should be done of its effectiveness versus cost compared to other safety improvements for where money would be best spent
- I think that two sets of strips are even better than one down the center. I feel as though once you hit the center strip, it may be too late as you are already crossing into the opposing lane.
- It is more important that the roads are free of hazards as potholes and that the center line is brightly and clearly painted!! I have driven at night and in rain on roads where the center line is almost invisible and that is VERY dangerous. Therefore, rumble strips would be helpful. If money is an issue and it is, Paint is cheaper.
- I drove in a snow storm with very poor visibility and the CL rumble strips were a must for helping me place correctly on the road.
- I think they are great especially the reflective ones.
- For what it's worth, I am a retired MDOT Traffic Safety engineer and worked with Dave Morena of FHWA-Lansing in studies that led to enhanced roadside rumble strips, and initial studies of other states experiences with center line rumble strips. Mr. Morena "pounded" many desks to get Michigan on board with implementing these two rumble strip programs. I don't believe he ever got deserved credit for his commitment to this definite safety improvement. Thank You.

- Debris from driving over the rumble strip can be a negative. Experienced an unexpected benefit from rumble strips, both centerline and edgeline, during heavy snow when the road was covered. Helped to keep the vehicle in the proper lane.
- I think centerline rumble strips deter safe passing. But not only that, I personally attempt to time my passing maneuvers at intersections or across bridges wherever there is a gap in the rumble strips. Obviously I do not violate the pavement markings which permit passing in these locations. I also think that centerline rumble strips cause unnecessary pavement degradation. The centerline pavement joint is already prone to deterioration and grinding into it just makes the deterioration worse and faster.
- The only thing that gets bad in Michigan is during freeze/thaw sometimes that area can get icy.
- One problem with the way the strips are installed is that they damage the roadway in a way that makes them more susceptible to pot holes. US-37 centerline is a mess a few years after the installation of the rumble strips. They provide a safety advantage but may become a hazard and increase road maintenance.
- I believe that centerline rumble strips improve the safety by warning the distracted drivers especially during the night
- If the cost doesn't outweigh the benefit.
- The strips seem to cause road pavement deterioration
- They help immensely when driving at night during a snowstorm to stay in the roadway.
- They can be of help in sub-urban and in some urban conditions also, apart from rural roads.
- Went to school at Michigan Technological University. Many times driving along US-41 visibility was very low due to snow. The center rumble strips helped very much as I could not see beyond my hood and the rumble strips were the only indication of if I was staying on the road or not.
- Useful provided the locations are chosen wisely and the rumble strips are not placed everywhere.
- I do live near a freeway where edge rumble strips are installed. They are a bit noisy at times. I fully support installing the center line versions on all two-way roadways. There are too many distracted drivers out there with the cell phone texting and general smart phone usage while driving. They are very inexpensive and effective.
- Excellent safety measure. Has there been any study to determine if they shorten the life of the pavement?
- I was in a snow storm on M25, which is the road that I live on and travel 30 miles every day to work, if it wasn't for the strips I probably would have been in the ditch or even could have been worse, I think that they are a wonderful thing
- They are helpful in so many ways....many times this winter I was in white outs and the strips helped me find my way , when it's pouring rain and you can't

see they show you where you're at ... So from personal experience I believe they make a big help in saving lives.

- I believe they are beneficial on rural roads with the consideration of noise near residential areas.
- Overdone and annoying
- Center rumble strips need to be evaluated along with other road improvements like paved shoulders in terms of overall value and not just as an independent element.
- They are life savers and should be used when applicable.
- I drive many of the 2 lane highways in the Upper Peninsula of Michigan in inclement weather and have been impressed with the effectiveness of the centerline rumble strips in times of poor visibility (darkness and rain especially).
- I am from Minnesota DOT. I wanted to see the survey questions. I have answered the questions as neutrally as possible, so as not to affect the results.
- Sudden winter white out conditions would be impossible to drive in if it weren't for the centerline rumble strips.
- I love rumble strips!
- I feel that they are not helpful to me (my driving habits), but may be to other people. I don't drive when I am tired and do my best to not be distracted. However, that is not the case with many other drivers and if they are there to keep them alert and keep me safe, I am all about them. I would like to note that I have heard complaints from people who do live near highways that have the centerline rumble strips who despise them because of the noise when people drive on them and I know of people who purposely drive on them to annoy the said people who live by them because they know it bothers them.
- When it is very dark or when visibility is low, it helps when you cross the centerline you can hear it first.
- They are very useful in the winter when you cannot see the paint lines. They should also be installed in the few concrete sections of roadway in the Upper Peninsula.
- I've been told by those who live on routes where the rumble strips were installed it that the noise is quite load and annoying. So to make a blanket statement that centerline rumble strips should be installed on more state roadways has to be considered first.
- Bad for the condition of our roads. Some over states don't cut rumble strips as deep and it still gets your attention if you drive across them. Why not pass laws against: texting, talking on a phone; eating, drinking anything, reading, ect. that distracts drivers. THEN ENFORCE THEM!!!
- I think the strips along the road shoulder are beneficial also for alerting drivers when straying off course. I support the cable-like median dividers on highways also.
- If people would stay off their cell phones and pay attention we wouldn't need them. But because of that I do like the idea.
- Thank you so much for installing them. I truly believe they save lives!

- I love them - especially on M-115
- They retain water that spills over on both sides of the center line. My concern is that in cold weather it could turn into black ice.
- Where I live is on a state highway. We have been here for 30 years and never has there been an accident in front of or near our residence. These strips are very noisy. We live 900 feet off the road, in the woods and still find the noise annoying.
- I have never seen centerline rumble strips. I've had to drive over shoulder rumble strips in construction zones. It sounds like a good idea.
- My definition of center-line rumble strips is the intentional sets of depressions that are pressed into the center-line of the roadway to make noise when tires pass over them. So--that's the assumption I've based my responses on. I think the idea is interesting, but I have no way to know if they've been statistically proven useful. I also wonder if the water & ice that collects in the depressions contributes to accelerated roadway deterioration.
- I believe that rumble strips would be helpful be on the right, ditch, side of two lanes roads also.
- EXTREMELY ANNOYING!!!!!!!!!!! Get rid of the center line strips.
- One downside of centerline rumble strips is the additional noise pollution as the noise can be heard further away (or at least clearer) than usual traffic noise. Two lane highways are usually close to residences and the tradeoff of potential prevented crashes versus residents' peace should be considered.
- There is no remedy for getting the water out after it rains. Has anyone in MDOT driven down M-60 between Spring Arbor and Jackson? Pothole city! It is frickin stupid. Potholes that have to be patched or have been patched. It is like the $36, 000 sidewalk at the capital--my god when does the stupidity end?
- Way to much noise, and they hold stones, dirt and salt and keep the road wet longer! That can cause the roadway to ice up! Why do they have to be so deep? I live on m100 near Potterville and when trucks run on them, it can be heard for miles. Cars will not move over for people on bicycles, I know I don't want to either! Let's spend money fixing the roads that need fixing, not making my life miserable!
- My husband & I traveled from Shanty Creek area this past week & drove through heavy rain & we thought the strips help us very much. We would like the state to consider having them on all the main routes & some other areas where accidents might happen. We would be willing to pay an one time extra tax to have these centerline rumble strips because they are an essential safety device & not that expensive to install.
- I live on a road where we have them. The noise is horrible. You can even hear it with the windows closed. I am afraid to pass someone walking or riding a bike because it is so loud I am worried about scaring them. We have people just riding on them for the heck of it which is awful. I cannot stress enough how loud the noise is. Our road is 55 mph with a lot of semis. I have lived here for 40 years and it has ruined this area.
- When they were put on m-60 the road seem to just fall apart from freezing and thawing.

- I drive a motorcycle. The only thing that I do not like about rumble strips is that they accumulate dirt, and when it rains, cars passing through dirt and water at you. It's even worse with trucks.
- Love them on a foggy morning or during a heavy down-pour!
- They seem to be a major waste of time. If you happen to be riding a bicycle and a car wants to get by they are often reluctant to move over, because of the rumble strips. We spend a lot of money redoing roads, then we chop into the new road surface; what a waste!
- I think centerline rumble strips should be installed on all 2 lane roadways I have seen too many close calls on roads without them.
- These are a great addition to our roads. We need more!
- Some strips are bone jarring. Could be an intensity (depth) to them depending on the specifics (speed limit, curves, special conditions) of the road.
- I believe these rumble strips are terrible on tires. I've spent many an irritating drive home on country highways behind tractors traveling 20 mph only because I don't want to prematurely wear my tires out. It is definitely a good way to promote road rage. While they may snap someone back to attention when they are dozing or texting, I don't believe they avert many accidents. During inclimate weather, they only seem to create ice pockets down the middle of the route.
- They are a good reminder for those distracted/tired drivers but it won't stop a drunk driver. The noise kind of shocks you and makes you think, am I in my lane?
- I also like the side line rumble strips. They are greatly helpful in fox, dark and rainy nights where the center line doesn't show from being wet, and very helpful in snow storms!
- My best example of a reason to install the center line rumble strips was when I was driving on US-2 during a decent snow storm. With the road being snow covered and snowing, it was hard to see where I was on the road, but with the center line rumble strips and the side rumble strips, and that they make different sounds, I could easily stay in my lane. These center line rumble strips are very useful and would love to see more of them!
- One question I would have is if they cause any damage to tires. Also, people need to be cautious not to be alarmed when they hear/feel the rumble strips and then swerve too quickly to get back into their lane.
- They are a lifesaver on snow-covered roads in winter.
- I would have no issues with the addition of strips on State roads and highways. However, I live in an area where a lot of roads never even get center lines painted due to the width, low traffic volume and cost. I have also noticed that roads with the center rumble strip seam to require more patching and sealing maintenance in the area of the strip due to the stress caused on the center seam of the roadway. This maintenance would add additional cost and decrease the lifetime of the road surface.
- The rumble strips hold the salt brine in the winter operations and don't let the salt do its job, consequently using more salt to clear the outer portions of the roadway. The standing water in the grooves also is deteriorating the older

blacktops, creating necessary patching in the most dangerous locations for workers. The noise if front of homes is unacceptable in a rural area. They build sound barrriers in the cities, then create unnecessary noise in the rural areas. A study should be made to prove they are not cost effective from a maintenance standpoint and probably not from a safety standpoint either.

- Possibly lessen the depth, to decrease noise.
- Centerline rumble strips are a valuable safety factor during inclement weather at night when the painted center lines are old or not reflective like they were years ago. They should be standard.
- Seem to work well, might want to put them on the right side lane where there are drop offs with no barriers or deep ditches.
- I agree with the safety benefits of their use in the center of two-lane highways in rural areas. However, I believe they are too close to the edge of the road when used on both sides of a divided highway / interstate. There is too little "margin for error" and it makes the lanes seem tighter when traveling at 70 MPH. I would rather see them pushed more to the edges of the paved surface.
- They could be more narrow and still serve the same function.
- I was slow to accept the strips. The damage to the center-line increases the likelihood of premature failure at a point that is already weak. It also increases the cost of properly repairing that area when it is repaved. But I have to admit I have used it for a guide in heavy snowstorms. I also know many (if not all) plow drivers use it for a guide in low visibility snowstorms which are common up here. With all the funding issues Michigan has, I am concerned about maintenance costs but have to admit they have improved safety.
- Junk tends to accumulate in these things and I have had many objects enter my tire. Most likely they were from them, as I need to cross them every day to turn down my street.
- I like the idea of the rumble strips. But I wonder does it break down the quality of the road faster than a road without rumble strips?
- But before you feel the need to put rumble strips on more roads, the need of the roads need to be updated and repaired. Putting asphalt on top of asphalt on top of asphalt creates a dangerous scenario, the mess grabs tires and throws cars, trucks etc. one way or another. Have to see the bigger picture!!!
- Our roads need so much work, I don't see how this could be a priority.
- I think they are great. I bet they have lessened the accidents on M-52.
- Invaluable when driving through snowy conditions. They have kept me out of a UP ditch on more than a few occasions.
- Can they be installed in a pattern so that when driven over a musical rhythm can be heard, that would be fun.
- On newer roads they should all have them. However some roads where they were placed were too far deteriorated and caused the pavement to fail prematurely
- Rumble strips are a danger to cyclists, drivers nearly always pass dangerously close on roads that they are cut into. It seems people are afraid to cross the strip

- As a cyclist I "like" hearing the rumble when a car is passing me, that way I know they are making an attempt to move over. Other times I wonder if the *won't* move over because they don't want to cross the rumble strip???
- I live where it snows heavily, and the centerline rumble strips are essentially for me when I can't see the lines due to lighting issues or snow covering the roads.
- They help the most in bad weather, snow, heavy rain, fog. It gives me a lot more confidence that I am still in my lane that I can't see. I miss them in other states, although Wisconsin has them in spots.
- I think the rumble strips are a good idea on highways and interstates but the cost would outweigh the benefit on rural back roads.
- They are very noisy, especially at nighttime and make it very hard to sleep when you hear the vehicles running over then while passing other vehicles.
- I believe they are helpful but they open up the center of the highway to water and ice, etc. causing the center of the road to deteriorate much quicker causing holes in the center of the road.
- They should be on every road in the state!! Saved my life one morning on M28 during white out conditions east of Marquette!!!
- Must work with side rumble strips too. It protects cyclists as people may swerve further from center to avoid the noise.
- It is important to think of all roadway users when installing rumble strips. They can be very inconvenient to bicyclist.
- It’s a great improvement on the road with little light
- I live on M-13 in Saginaw County. During the summer when windows are open it gets to be a little annoying, but if it can save a life I can deal with it. In two experiences in my life I think it could have changed the outcome of accidents. My brother's childhood friend is still recovering from a near death accident while driving sick and drowsy. If rumble strips would have been in place before his accident it might not have been so severe. My husband was driving home from work at 4 am and crossed into oncoming traffic and ended up in the ditch. Thankfully he was okay and no one was coming in the other lane, but maybe that too could have been avoided. The people that complain about the noise, care more about themselves.
- I make frequent trips to the UP and the centerline rumble strips are a great boon when it's after midnight and I'm trying to finish the trip!
- Another place they should be considered are places where lane changes aren't allowed and crashes are common, such as I-75 near 9 Mile and near Joslyn Rd. Another comment about them is that the noise alerts me when an oncoming vehicle is crossing the center line so I can watch out.

APPENDIX IV – PAVEMENT DESIGN AND MAINTENANCE PERSONNEL'S IMPRESSION SURVEY

Wayne State University Transportation Research Group
Evaluation of Non-Freeway Rumble Strips – Phase II
Pavement Design and Maintenance Personnel's Impression Survey
http://www.surveymonkey.com/s/rumblestrippavement

The purpose of this survey is to collect information from pavement design and maintenance personnel regarding the performance of centerline rumble strips on Michigan two-lane highways. The results of this survey will provide important insights in to future deployment of centerline rumble strips in Michigan. Your input will also assist in formulating future strategies for expanding centerline rumble strips implementation on local road systems in Michigan and in other states.

Completed surveys can be mailed, faxed, or e-mailed to our care, or the survey can be completed online at: http://www.surveymonkey.com/s/rumblestrippavement. Your participation in this effort and your responses to these survey questions would be greatly appreciated. If you have questions about this initiative, please feel free to contact MDOT project manager Jill Morena at morenaj@michigan.gov. Thank you in advance for your assistance. This survey response will be kept confidential. Your name and contact information will be used by the researchers for obtaining clarification of responses if necessary.

1. Name: ____

   Title: ____

   Office Phone: (_____)-______-____________ E-Mail: ___________________________

2. To what extent do you agree with the following statement?

   The installation of centerline rumble strips on MDOT two-lane highways improves safety on such roadways.

   □ Strongly agree □ Agree □ Uncertain □ Disagree □ Strongly disagree

3. Do you believe that centerline rumble strips damage/weaken pavement in the **short-term time period (1 to 3 years)**? (If your answer is "No," proceed to Question 5)

   □ Yes □ No

4. Please comment on the suspected nature and cause of short-term pavement damage. If you have a specific road segment in mind, please provide some specific details of the occurrence of damage. (Include location, type of damage, photos, etc.)

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5. Is it your impression/experience that centerline rumble strips damage/weaken pavement in the **long-term time period (greater than 3 years)**? (If your answer is "No," proceed to Question 7)

   □ Yes   □ No

6. Please comment on the suspected nature and cause of long-term pavement damage. If you have a specific road segment in mind, please provide details of damage you believe maybe attributable to rumble strips. (Include location, type of damage, photos, etc.)

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7. What type of potential pavement distresses could be related to centerline rumble strips?

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8. Does your pavement design/maintenance strategy change for a road with centerline rumble strips?

   □ Yes   □ No   If yes, how does your strategy change?

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9. What is the potential difference, if any, in pavement performance over time when installing a centerline rumble strip into an old pavement versus a new pavement?

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10. How do rumble strips effect winter maintenance operations?

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11. Please provide any other comments you may have regarding the use of centerline rumble strips on two-lane highways.

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Completed surveys can be e-mailed, faxed, or mailed to:

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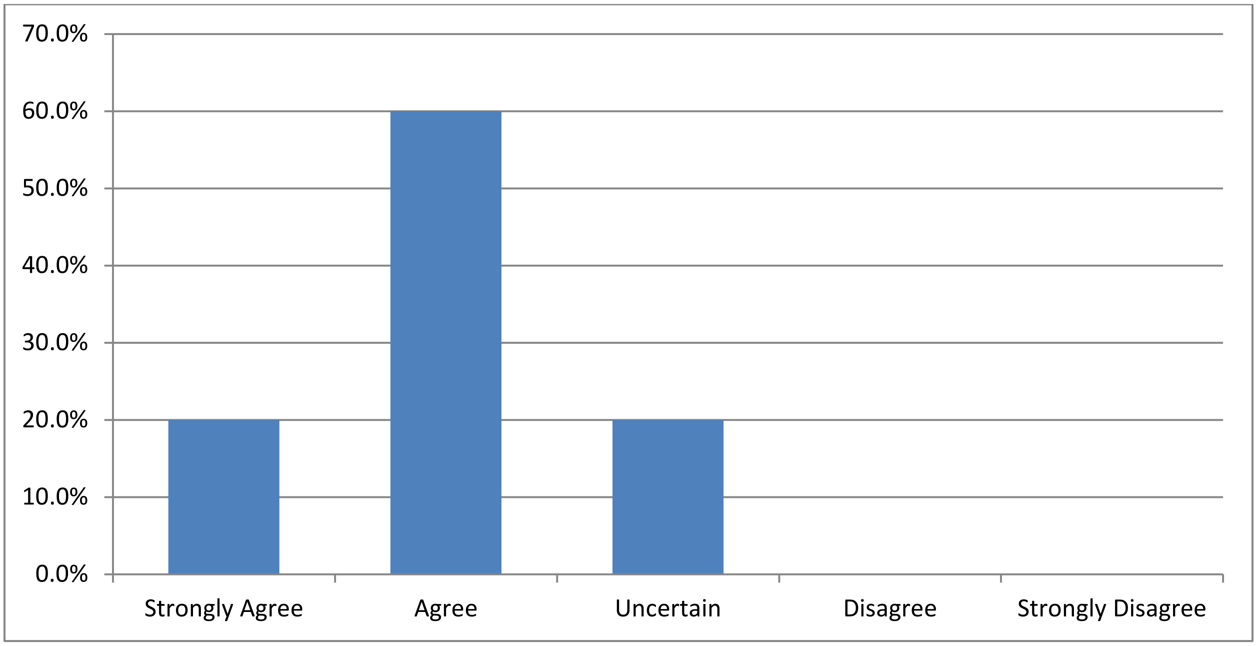
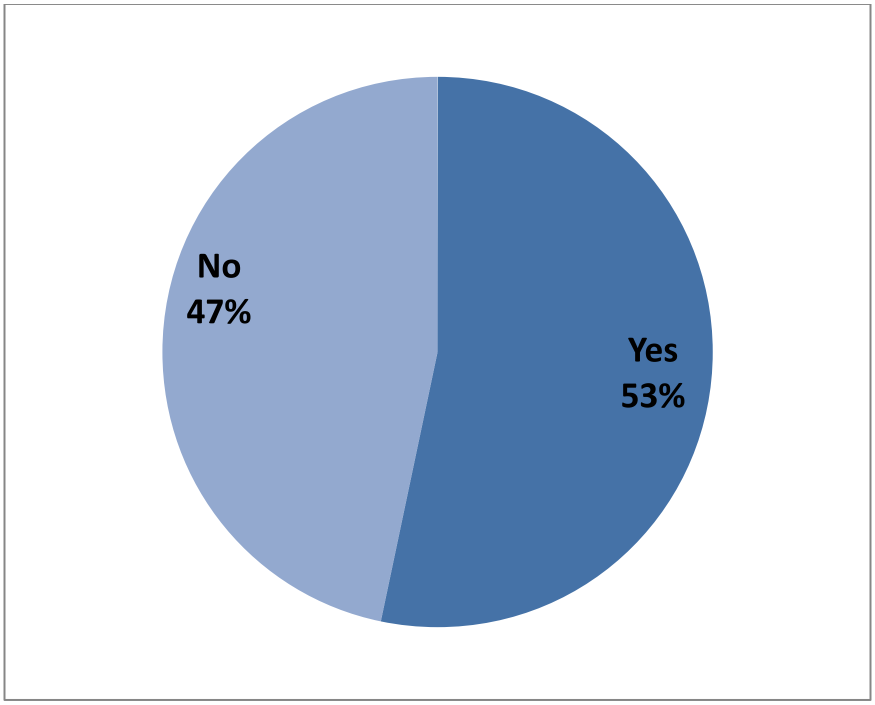
Pavement Design and Maintenance Personnel's Impression Survey

2. To what extent do you agree with the following statement? "The installation of centerline rumble strips on MDOT two-lane highways improves safety on such roadways."



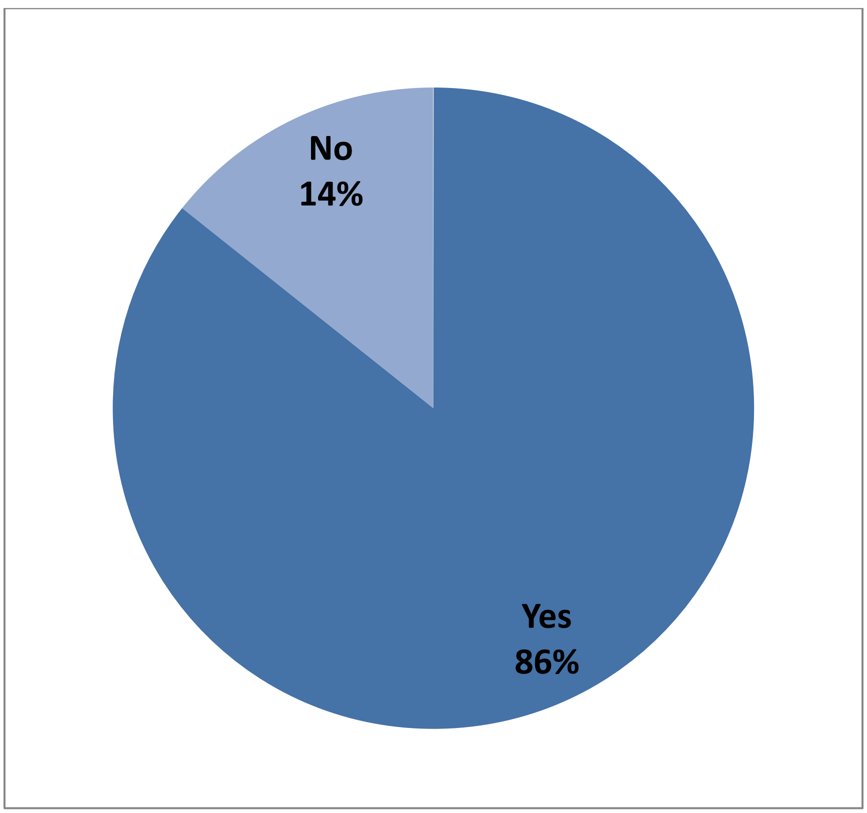
3. Do you believe that centerline rumble strips damage/weaken pavement in the short-term time period (1 to 3 years)? (If your answer is "No," proceed to Question 5)



4. Please comment on the suspected nature and cause of short-term pavement damage. If you have a specific road segment in mind, please provide some specific details of the occurrence of damage. (Include location, type of damage, photos, etc.)

    - Road falls apart faster in Rumble Strip area. Pot holes develop quicker. Center line crack develop quicker.
    - The rumble strips are a big safety improvement. But for maintenance they are bad ideas. We have problems on all our two lane road because of them. Water and salt from winter sit in the strips then the water get in the cracks and under pavement. There is no good way to seal cracks in the strips.
    - Pavement join is on the centerline..rumble strips are also on the centerline holding water. Water seeps out of the rumble strip and into the pavement joint causing failure after freeze thaw cycles.
    - Short-term damage is more prevalent when the strips are installed on surfaces that are not brand new.
    - Water pools in rumble strip and will refreeze causing larger rumble strips
    - The rumbles provide a place for water to infiltrate into the pavement structure at a location that already has issues with compaction.
    - Damage to open-graded friction course pavements has been observed.

5. Is it your impression/experience that centerline rumble strips damage/weaken pavement in long-term time period (greater than 3 years)? (If your answer is "No," proceed to Question 7)



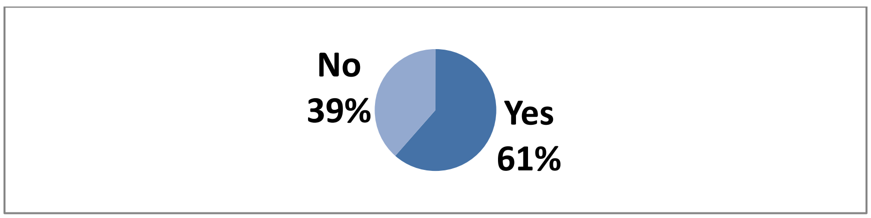
6. Please comment on the suspected nature and cause of long-term pavement damage. If you have a specific road segment in mind, please provide details of damage you believe maybe attributable to rumble strips. (Include location, type of damage, photos, etc.)

    - Road opens up quicker allowing water to seep into/under road surface causing road to fall apart sooner and reducing life of road.
    - M-37 from Hastings to Middleville, center line is falling apart. The strips weaken the road surface.
    - Road bed (at the centerline joint) being saturated with water year after year.... freeze thaw after freeze thaw.
    - Have noticed several locations that between the asphalt seam and the rumble strips the center opens up and breaks down
    - Water is held in the rumble strips, at the centerline seam.
    - Same as with the short term, it has just had longer to break down the pavement near the centerline.
    - Long term damage observed has been in pavements that show centerline or edge distress prior to the rumble being ground in.
    - They hold water and over a period of time I believe they will allow water into the seam sooner.
    - Anytime you break the surface seal of a material there is a higher potential for water intrusion. Water penetration causes damage.

7. What type of potential pavement distresses could be related to centerline rumble strips?

    - Premature surface failure
    - The distress comes from cutting a half inch of pavement out of the crown of the road.
    - Longitudinal cracks
    - Pot holes
    - My biggest concern was water freezing in the depressions and causing problems.
    - Depending on the wearing surface that is present, you can have stone loss, raveling, delamination.
    - Mainly spalling of the HMA behond and between the rumbles.
    - Separation and unraveling
    - Cracking

8. Does your pavement design/maintenance strategy change for a road with centerline rumble strips?



If yes, how does your strategy change?

- During winter salt tends to hold in Rumble Strips more because of new 25 MPH rule.
- As for maintenance we have to spend more time fixing and repairing the center line because of the strips.
- Ice build up in Rumble Strip. Centerline hard to clean.
- Can’t salt the centerline on the way back. You must salt outside of the centerline each way. Otherwise the salt just lays in the rumble strips.
- Recently our double chip seal spec has been changed to eliminate both courses going over the rumbles. There is a feeling the 2 courses fill the rumbles in too much.
- Choose the appropriate pavements up front. No pavements that currently exhibit centerline or edge distress and no OGFC pavements. For all other pavements I would recommend sealing the centerline with either a fog seal or rejuvenator after grinding the rumbles in.

9. What is the potential difference, if any, in pavement performance over time when installing a centerline rumble strip into an old pavement versus a new pavement?

- Quicker pavement surface failure
- Maintenance doesn't install the strips. We just try to keep the center line together after they are installed.
- Cracking in Concrete, shelling in Asphalt
- Strips appear to hold up better when installed in new surface. When installed on older surfaces, the strips appear to deteriorate more rapidly.
- No idea. I wouldn't think it would make a difference if the material was sound and in good condition.
- Installing rumbles into an older pavement is more risky as you don't know how well that longitudinal paving joint is going to hold up.
- As mentioned earlier, it has more to do with the integrity of the existing HMA pavement.
- Don't know. I would suspect that the older pavement would crumble sooner.
- It would depend on the condition and value of initial compaction.

10. How do rumble strips effect winter maintenance operations?

- Same as Q#8
- Salt gets in the strips and stays there. This causes water to sit in the strips and refreezes.
- Hard to clean centerline.
- Can’t salt the centerline on the way back. You must salt outside of the centerline each way. Otherwise the salt just lays in the rumble strips.
- They help hold salt which helps melt the road longer.
- We get more customer complaints when our trucks ride the center lines.

- They are great for winter maintenance operations. Several agencies have told me that the centerline strips help the drivers know where they are at on the roadway when visibility is limited in heavy wind and snow conditions.
- I do not know.
- Not my area of expertise.
- They hold the salt brine and doesn't allow the water to be as fast acting as it could be.

11. Please provide any other comments you may have regarding the use of centerline rumble strips on two-lane highways.

    - Before Rumble Strips in center, Rumble Strips were just on outside shoulders. While working on road if you hear Rumble you know something was on shoulder. Now you don't know if it is someone crossing center line or on the shoulder, therefore causing employee's to look back to see where the vehicle is (shoulder or center) causing delay for employee's to move out of the way.
    - We can't put a price on saving someone's life. But we need to make crown of road stronger if we plan to keep cutting out for the strips. (They hold water and the water get through the cracks in the winter. Then freezes and in the spring we have potholes.)
    - Extremely noisy if you live on that road section.
    - We have received numerous comments from the folks who live on our hwys. where the strips are installed. Many feel the strips could be shallower or spaced differently to produce less noise in their homes.
    - I have been surprised that more damage has not shown up from rumble strips based on MDOT's experience with poor longitudinal density. Safety provided has been studied and acknowledged by FHWA sponsored research. Preventive maintenance activities have not been done in Michigan to date and should be incorporated into the rumble program.
    - I believe that the safety aspect outweighs the down side of not getting the pavement life.
    - Noise in the country.