Installation Guidance for Centerline and Edgeline Rumble Strips in Narrow Pavements

Final Report
September 2017

Center for Transportation Research and Education

MIDWEST TRANSPORTATION CENTER

IOWA STATE UNIVERSITY
Institute for Transportation

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16. Abstract

Shoulder rumble strips (SRS) and centerline rumble strips (CLRS) on two-lane rural highways are proven safety countermeasures. Placement of both SRS and CLRS can usually be accommodated within wide pavements (24 ft or greater paved width) without issue. However, proper placement of one or both is less straightforward for highways with paved widths less than 24 ft. Placement becomes especially difficult as widths approach 20 ft.

Contributing factors such as traffic volume, roadway alignment, and the posted speed limit may suggest the use of one type of rumble strip over another. However, limited guidance currently exists regarding the minimum paved width necessary to install both SRS and CLRS, or which of the two to install when the installation of both is not feasible.

The purpose of this study is to provide guidance to assist county road agencies, as well as the Iowa Department of Transportation (DOT), in determining when to install rumble strips based on various site-specific factors.

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EXECUTIVE SUMMARY

Rumble strips are milled or raised patterns installed in a longitudinal direction near the centerline or edgeline of a roadway. Rumble strips provide both a tactile and audible alert to motorists who are drifting from their intended lane of travel along two-lane rural highways. Two general types of rumble strip installations are common: (1) centerline rumble strips (CLRS) are placed between opposing lanes of travel to limit the potential for head-on or opposite-direction sideswipe collisions, and (2) edgeline rumble strips (ELRS) or shoulder rumble strips (SRS) are installed on the shoulder of the roadway to decrease run-off-road crashes.

Research has demonstrated that the use of CLRS and SRS/ELRS, both individually and in combination, are effective low-cost countermeasures. However, many agencies have minimum pavement width dimensions that must be met for rumble strips to be installed along a roadway segment. These minimum widths help to ensure that motorists are able to travel comfortably while limiting the number of times the rumble strips are struck inadvertently. On roadways with regular pedestrian and, particularly, bicycle traffic, minimum shoulder widths are generally established to ensure that sufficient space is available for such non-motorized users.

Unfortunately, limited guidance is currently available regarding the minimum pavement width necessary to install both CLRS and SRS/ELRS in combination, or which of the two to install when the installation of both types on one segment may not be feasible. The purpose of this study is to provide guidance for installing rumble strips on narrow pavements based on various site-specific factors, such as traffic volume, roadway alignment, and shoulder type.

This study involved an analysis of historical crash data for segments with various rumble strip configurations in order to assess the risk of cross-centerline and run-off-road crashes. The crash rates for these configurations were compared to similar control segments without rumble strips while accounting for the effects of other pertinent factors, such as lane and shoulder widths. The research also involved a series of field studies of road user behavior to determine how the presence of rumble strips affected the lateral position of vehicles along two-lane highways on the primary (i.e., state-maintained) and secondary (i.e., county-maintained) systems throughout Iowa. Road segments with different cross-sectional characteristics (e.g., lane width, shoulder width) and varying combinations of rumble strip installations (i.e., CLRS only, SRS/ELRS only, or CLRS and SRS/ELRS) were observed. Control segments without rumble strip installations were also observed.

Lastly, public input was obtained at 10 Iowa Department of Transportation (DOT) driver's license stations across the state to gauge public perceptions of rumble strips. This survey sought feedback as to the safety effects of rumble strips as well as secondary effects associated with rumble strip installations, such as noise, effects on passing maneuvers, bicyclist issues, and so forth. These surveys were implemented in Iowa counties with known rumble strip installations to increase the probability that survey participants had experienced previous interactions with rumble strips while driving on the secondary highway system.

Segments with centerline rumble strips experienced 33.2% fewer cross-centerline crashes on average, with negligible differences in the rate of cross-edgeline crashes. Similarly, sites with edgeline/shoulder rumble strips experienced 16.1% fewer cross-edgeline crashes, with no adverse impacts on the rate of cross-centerline crashes. While the field studies showed that the presence of rumble strips introduces small impacts on the rates of encroachment (i.e., edgeline rumble strips increased centerline encroachment rates and vice versa), the overall rates of encroachment were quite small.

Based on the results of this research, recommendations and guidance are provided to assist agencies in determining scenarios in which the implementation of rumble strips is warranted. This guidance includes the prioritization of candidate locations based on characteristics such as lane width, shoulder width, and annual average daily traffic. Safety performance functions (SPFs) were developed that can be used to estimate the expected number of cross-centerline and run-off-road crashes for a segment with specific characteristics. These functions provide a means for conducting network screening to identify those locations where centerline and/or shoulder/edgeline rumble strips may provide the greatest benefit.

1. INTRODUCTION

Lane departure crashes, which occur when a vehicle crosses the edgeline or centerline of a roadway, result in nearly 17,000 fatalities annually throughout the US, comprising a majority of all fatal crashes (NHTSA 2014). Lane departure crashes are a particular concern on high-speed undivided highways, which are more susceptible to cross-centerline crashes, including head-on and opposite-direction sideswipe collisions. Centerline rumble strips (CLRS) and shoulder rumble strips (SRS)/edgeline rumble strips (ELRS) are common countermeasures to reduce lane departure crashes. These treatments provide a tactile and audible alert to motorists who drift out of their intended travel lanes. A 2011 state-of-the-practice survey found that at least 36 states in the US had implemented CLRS, covering more than 11,000 roadway miles (Karkle et al. 2013).

Several prior evaluations have assessed the safety performance of CLRS and SRS on high-speed non-freeway facilities. An early evaluation of CLRS installations along 210 miles of two-lane highways across seven states showed a 14% reduction in total injury crashes and a 25% reduction in head-on and opposite-direction sideswipe injury crashes (Persaud et al. 2003). Similar results were observed in subsequent evaluations of CLRS on two-lane rural roadways, including a study in British Columbia, Canada, that found a 29.3% reduction in run-off-road-left and head-on collisions (Sayed et al. 2010) and a Kansas study that found a 29% reduction in correctable cross-centerline crashes (Karkle et al. 2013).

The National Cooperative Highway Research Program (NCHRP) Report 641 provides an extensive evaluation of the safety impacts of CLRS, including data from extensive CLRS implementations in Minnesota, Pennsylvania, and Washington (Torbic et al. 2009). Head-on and opposite-direction sideswipe collisions were reduced by 37.0% and 44.5%, respectively, while total crashes and injury or fatal crashes were reduced by 4.1% and 9.4%, respectively. Crash reductions were found to be particularly pronounced on horizontal curves.

A recent Michigan study found CLRS to reduce total crashes by 15.8 to 17.2% and fatal target (i.e., cross-centerline) crashes by 44.2 to 51.4%, as shown in Table 1 (Kay et al. 2015). Interestingly, these reductions were most pronounced when CLRS were used in combination with SRS, even though the study focused only on centerline-related crashes.

Table 1. Reductions in crashes by type of rumble strip installed

	Percent Reduction in Crashes	
Crash Type	**CLRS Only**	**CLRS and SRS**
Total	15.8	17.2
Target	27.3	32.8
Fatal Target	44.2	51.4

Source: Kay et al. 2015

These data suggest that rumble strips result in fundamental differences in driver behavior that ultimately help lead to reductions in lane departure crashes. However, it is unclear whether CLRS, SRS, or a combination of the two treatments are most effective on narrower pavements.

Currently, numerous factors are considered when determining whether to install rumble strips on a given roadway location; however, specific installation standards are generally lacking, particularly for roadways with narrow pavement. This research addresses this gap through three specific studies:

- Chapter 3 presents the results of a crash analysis that was conducted to discern the impacts of centerline and shoulder/edgeline rumble strips on the frequency of lane departure crashes on the Iowa primary highway system.

- Chapter 4 provides results from a series of field studies that were targeted toward understanding how the lateral position of vehicles is affected by the presence of CLRS and SRS/ELRS while accounting for differences due to lane width, shoulder width, horizontal alignment, and other factors.

- Chapter 5 summarizes a road user survey that was conducted at Iowa Department of Transportation (DOT) driver's license stations across the state. The purpose of this survey was to discern public opinions toward rumble strips, including both the operational and safety impacts, as well as secondary impacts such as noise and bicyclist safety.

- Chapter 6 provides conclusions and recommendations to assist agencies in future rumble strip deployments based on the findings from this study.

2. LITERATURE REVIEW

Lane departure and run-off-road (ROR) crashes account for a large portion of the total traffic fatalities in the United States. Lane departure incidents can lead to a head-on collision with a vehicle traveling in the opposite direction. ROR crashes typically involve a single vehicle exiting the roadway and striking a fixed object. Both of these crash types present heightened risks for severe or fatal injuries to motor vehicle occupants when a crash does occur. According to the Federal Highway Administration (FHWA), 17,791 fatalities resulted from roadway departure crashes in 2014 (NHTSA 2014). This represented 54% of all traffic fatalities in the US. Both lane departure and ROR crash types are common on high-speed (55 mph) two-lane rural highways due to the nature of the typical roadway geometry on those roads.

Commonly used countermeasures to reduce the impacts of these crash types on two-lane rural highways are CLRS and SRS or edgeline rumble strips (ELRS). ELRS are generally installed directly on the edgeline of the pavement and, as such, are often referred to as "rumble stripes" because the edgeline marking is generally painted on top of the rumble strips. CLRS and SRS/ELRS provide both an audible and tactile warning to drivers of a potential lane departure situation. This alert can be used to gain the attention of inattentive or drowsy motorists as well. The purpose of this literature review of the state of the art is to document the impacts of CLRS and SRS/ELRS (both independently and jointly) on traffic operations and safety as well as to investigate supplementary issues such as noise pollution, impacts on passing maneuvers, and effects on non-motorized users. In addition, a review of available prioritization strategies for CLRS and/or SRS installation locations was conducted.

2.1 Impacts on Traffic Safety and Operations

An empirical Bayes (EB) before-and-after analysis was conducted to evaluate the effects of the combination of CLRS and SRS installed together on the same roadway (Persaud et al. 2016). Data were collected from three states (Kentucky, Missouri, and Pennsylvania) and analyzed to determine the effect that this combination of rumble strip installations had on safety. Ultimately, the presence of CLRS and SRS reduced head-on collisions by 36.8% and lane departure crashes (ROR, head-on, and sideswipe-opposite) by 26.7%. A similar study in Washington found a 63.3% reduction in lane departure crashes when CLRS and SRS were used in combination (Olson et al. 2013). Although the treatments are more effective on higher speed roads, locations with a posted speed limit of 50 mph saw a 49.2% reduction in target crashes; this can be compared to the 58.4% and 64.8% reduction in target crashes at 55 mph and 60 mph, respectively.

An additional rumble strip effectiveness study was conducted in Idaho utilizing historic crash data (2001–2009) on two-lane rural segments with recently implemented SRS (Khan et al. 2015). The study examined the effectiveness of SRS in consideration of the effects of other factors, such as traffic volume, roadway geometry, and the presence of paved shoulders. The results showed a 14% reduction in ROR crashes after rumble strip installations on approximately 180 miles of two-lane highway. The SRS were most effective on highway segments with a slight curvature and a right paved shoulder that was greater than 3 ft wide.

A Michigan study assessed the safety impacts of a statewide CLRS installation program that covered more than 5,000 miles of rural highway (Kay et al. 2015). SRS were installed during this time period if a paved shoulder greater than 6 ft wide was present. Results of the study showed that CLRS reduced cross-centerline crashes by 27.3% individually and by 32.8% when combined with SRS. Crash reductions were also observed in instances of adverse pavement conditions, passing maneuvers, and impaired driving situations.

A companion project in Michigan studied motorist behavior on 10 roadways during the periods before and after rumble strip installation (Gates et al. 2012). The study examined the effects of rumble strips on passing behavior, lateral lane placement, and travel lane encroachments (Gates et al. 2012). The results, summarized in Table 2, show improvements in vehicular lateral position when rumble strips were installed, particularly along horizontal curves.

Table 2. Changes in lateral position at locations with CLRS only or CLRS and SRS

CLRS Type	Segment Type	Left of Center		Centered		Right of Center	
		Before	After	Before	After	Before	After
CLRS Only	Tangent	22.3%	18.6%	36.3%	48.4%	41.4%	33.0%
	Left Curves	40.8%	19.4%	33.1%	54.9%	26.1%	25.7%
	Right Curves	6.3%	7.1%	24.7%	45.3%	69.0%	47.6%
CLRS and SRS	Tangent	32.9%	9.6%	34.9%	68.7%	32.2%	21.6%
	Left Curves	20.0%	4.5%	33.8%	72.5%	46.2%	22.9%
	Right Curves	21.5%	1.8%	34.6%	67.5%	43.9%	30.7%

Source: Gates et al. 2012

CLRS are generally shown to elicit more centralized vehicular lane positioning, an effect that is even more pronounced when SRS are used in combination with CLRS. In addition to improving lane positioning tendencies, rumble strips were also found to reduce the rate of both centerline and edgeline encroachments, indicating that vehicles were more likely to stay within the correct travel lane when rumble strips were present. These results were consistent on both tangent and curve segments. Ultimately, the combination of CLRS and SRS were found to improve lane keeping ability, which is a likely factor contributing to the significant reduction in target crashes that has been demonstrated after rumble strip installation.

2.2 Impacts on Noise

Despite the proven safety effects of rumble strips, some concerns have been raised as to negative consequences associated with rumble strip installation. One concern with the installation of rumble strips is the level of audible noise generated when a vehicle travels over the milled indentations. A survey of relevant research conducted in four states (Michigan, New Hampshire, Ohio, and Washington) showed that milled rumble strips can increase external noise levels by 5 to 19 decibels when compared to the baseline roadway noise generated without rumble strip installations (CTC & Associates LLC 2012). Similarly, noise levels inside vehicles were found to increase by 5 to 15 decibels when compared to the non–rumble strip baseline scenario. An additional study examined the different detectable sounds produced by three different rumble strip designs when traversed by a passenger car, a pickup truck, and a tractor trailer (Terhaar and Braslau 2015). The results of the examination revealed that while the design utilized in Minnesota was detectable within 1,000 ft of the roadway, the other designs (in California and Pennsylvania) were detectable from over 3,000 ft away from the roadside.

A continuation of the study considered the external and internal noise effects of additional types of rumble strip designs (Terhaar et al. 2016). The results showed that the external noise was a function of the rumble strip pavement depth; however, the depth was not significant when internal noise was considered because all rumble strip designs produced similar internal sound levels. An additional evaluation was performed that measured the increase in roadside noise associated with different centerline rumble strip depths and pavement surface types (Gates et al. 2013). From the study, it was determined that the milled depth of the rumble strip was the strongest predictor of the amount of detectable external noise; every 1/16 in. increase in centerline rumble strip depth was associated with a 2.3 decibel increase and a 1.4 decibel increase on hot mix asphalt and chipsealed pavements, respectively. The authors recommended that centerline rumble strips be milled to a depth of 1/4 in. to 5/8 in. in order to limit the level of external noise produced while still eliciting the necessary driver response.

Although the purpose of rumble strips is to increase motorists' attentiveness while driving, a study that analyzed the interactions between drowsy driving and rumble strip installations determined that after the initial vehicle–rumble strip interaction, subsequent interactions did not increase driver alertness (Watling et al. 2015). After working a full night shift, subjects were instructed to drive in a high-fidelity simulator that included a road with both CLRS and SRS. The average vehicle-rumble strip interaction occurred after about 20 minutes of simulated driving, followed by the next interaction 10 minutes later, on average. The next three vehicle-rumble strip interactions were an average of 5 minutes apart. The findings from this research indicated that after initial contact with the rumble strip, the general effectiveness of the audible and vibratory warning was reduced significantly for drowsy motorists. Additionally, the likelihood of crossing another rumble strip increased after the first interaction, as did the physiological and subjective sleepiness of participants as determined by the Karolinska Sleepiness Scale (KSS), which is a self-reported measure used to evaluate the level of sleepiness on a nine-point Likert scale.

Similar results were cited by an expert panel convened in a joint effort by the National Center on Sleep Disorders Research and the National Highway Traffic and Safety Administration (NCSDR/NHTSA Expert Panel on Driver Fatigue and Sleepiness 1998). The expert panel noted that rumble strips placed on high-speed, controlled-access, rural roads reduced ROR crashes by up to 50%; however, the panel recommended that this audible alert should be viewed by motorists as an indication of impairment and that adequate sleep should occur immediately before any additional driving occurred.

2.3 Impacts on Bicyclists and Motorcyclists

Another concern with the installation of SRS is the effect they may have on bicyclists. The bicyclists most affected by SRS are those traveling at high rates of speed, which is common in rural areas where grades tend to be steeper and pedestrians are less likely to be present. SRS have the potential to cause cyclists to lose control and present an increased threat on roadways with speeds greater than 35 mph (O'Brien et al. 2014).

A study in North Carolina determined that bicyclists feel more comfortable while maneuvering through larger sized rumble strip gaps (O'Brien et al. 2014). The researchers determined that the current practice is to separate an SRS series with 12 ft gaps; however, the study recommend a 16 ft to 18 ft gap between an SRS series to increase a bicyclist's ability to maneuver while still alerting drivers who may leave their lane at a departure angle of 3 degrees or more.

Bicyclists may also be affected by the decreased likelihood of a vehicle crossing over the CLRS while passing them. Research performed in Michigan found that vehicles were less likely to contact the centerline (and thus traverse the CLRS) while passing a bicyclist, which may crowd the bicyclist during the passing maneuver (Savolainen et al. 2012). However, motorists were more likely to ride over the CLRS while passing a group of bicyclists as opposed to a single bicyclist. Additionally, the lateral positioning of the bicyclist also heavily impacted the lateral positioning of the passing vehicle. Vehicles did not cross the CLRS as often when the bicyclist was in the middle of the shoulder; a greater crossover response was noted when the bicyclist moved closer to the roadway edgeline. These findings indicate that the CLRS will be crossed when the driver determines the maneuver is essential for the safety of both parties.

The concerns of bicyclists were also considered in a study that gathered feedback and recommendations from bicyclists regarding six unique rumble strip configurations that were designed with "bicycle-friendliness" in mind (Elefteriadou et al. 2000). Following the feedback solicitation, each unique rumble strip configuration was tested to check for any degradation in motorist performance when compared to typical rumble strip designs. Two specific rumble strip configurations were considered safest for bicyclists and motorists alike. These selected patterns were installed in the field, and data were collected to analyze their effectiveness.

An additional concern with the installation of CLRS is the impact they may have on motorcyclists. Similar to the measured effects SRS have on bicyclists along rural highways, a growing concern has developed to determine if a similar effect is experienced by motorcyclists when CLRS are present.

A study on rural Minnesota highways examined the potentially detrimental effects that CLRS may have on both two-wheeled and three-wheeled motorcycles from 1999 to 2008 (Miller 2008). An analysis of all relevant motorcycle-involved accidents revealed that CLRS were not a factor in any of the 29 observed accidents. A 40-hour roadside field observation also noted no visible rider correction or overcorrection maneuvers on rural highways where CLRS were installed. A control condition on a closed circuit was also tested with 32 riders who had a varying range of experience with motorcycle riding. Interviews with these individuals determined that riders had no difficulty or concern when encountering CLRS on a rural highway.

2.4 Rumble Strip Specifications

Some researchers have looked into the optimal pattern or shape of the rumble strip itself. A private company in Kansas designed a football-shaped rumble-strip pattern that can be implemented on both the shoulder and centerline of the roadway. The purpose of developing the rumble strip design was to include rounded corners that allowed for wind and rain to “self-clean” the rumble strips, as well as to accommodate a more bicycle-friendly design.

Independent research by Kansas State University researchers compared equivalent rectangular rumble strips to the proposed football-shaped design (Rys et al. 2008). The research determined that there was no difference between the two designs in terms of water and debris collection or interior sound and vibratory production, although bicyclists preferred the football-shaped design over the traditional rectangular design. Ultimately, there was no significant benefit derived from the football-shaped rumble strips when compared to traditional rectangular rumble strips.

Further analysis of the overall rumble strip shape was performed to discover the optimal dimensions for a rumble strip based on the vibrational effects sensed by the motorist (Liu and Wang 2011). The study determined that the rumble strip width should be around 7 in. (180 mm), while the depth of the milled indentations should be between 3/16 in. (5 mm) and 10/16 in. (15 mm). These dimensions provided a sufficient jerk ratio, or a sufficient rate of change in vehicular acceleration relative to the roadway. Ultimately, the jerk ratio is a numerical measure related to the act of the motorist striking the rumble strips and maneuvering the vehicle back into the appropriate lane.

2.5 Pavement Impacts of Rumble Strips

The milled indentations created by rumble strips have also generated concern regarding the potential reduction in service life of the pavement on which the rumble strips are installed. Because the amount of the surface area of the pavement that is exposed to the elements is increased when rumble strips are installed, a common concern with rumble strip installations is the potential impact on the service life of the base pavement. The milled indentations may also allow for water to pool on the roadway surface for a longer time than anticipated when the roadway was designed.

A survey of professionals was conducted to investigate the long-term maintenance effects, if any, that rumble strips have on hot mix asphalt pavements (Watson et al. 2008). Results from the survey indicated that respondents noted distresses in milled rumble strips as well as concerns that the rumble strips had caused distresses in nearby pavement. To counteract this effect, the researchers recommended applying a cationic rapid-set polymer modified diluted (CRS-2pd) fog seal over the rumble strips immediately after milling. The purpose of this fog is to ensure that the surface is sealed from the elements soon after the milling process. The sealing should also slow the growth of cracks around the rumble strips over time, thereby increasing the service life of the pavement after rumble strip installation.

2.6 Guidelines for Rumble Strip Implementation

Although the CLRS and SRS have proven to be low-cost safety countermeasures that reduce lane departure crashes, there are no universal prioritization guidelines or standards that help decision makers determine the roadways on which the installation of rumble strips would be most effective, given a limited budget.

A survey of the Wyoming DOT (WYDOT) found that a variety of non-uniform factors are used when determining where rumble strips should be installed (Ahmed et al. 2015). A group of 45 WYDOT engineers responded to the survey and indicated that roadway features such as area type, traffic volume, speed limit, lane width, shoulder width, crash history, pavement type, and pavement depth were all factors that govern rumble strip installation.

Another survey determined the current practices that 41 state DOTs use when choosing locations to install rumble strips (Smadi and Hawkins 2016). The responding agencies noted influencing factors that were different than those found during the WYDOT survey. The presence of homes nearby, the functional class of the road, current pavement condition, and roadway alignment were all considered by at least one agency when selecting locations for rumble strip installations.

Another survey of statewide literature, state DOT and FHWA representatives, and rumble strip contractors found that documentation supporting the installation of rumble strips on narrow pavements was very uncommon (Elefteriadou et al. 2001). In addition, a multitude of various factors were considered by the surveyed states when determining minimum requirements for rumble strip installation on two-lane roads with narrow shoulders. Salient factors included average daily traffic (ADT), speed limit, shoulder width, and pavement thickness.

Of the 39 states surveyed, two states required the consideration of ADT when selecting rumble strip installation locations, while four states had a minimum speed limit requirement. Only two states surveyed (Arizona and Oregon) reported actually installing rumble strips on two-lane roads with narrow shoulders; however, the safety effectiveness of the installations was not available at these locations for further analysis.

The Michigan DOT (MDOT) has very specific guidelines as to where CLRS should be installed on rural high-speed roadways (WSU-TRG 2015). MDOT applies CLRS to all rural two-lane and four-lane roadways in either passing or non-passing zones where the existing speed limit is 55 mph and the lane and paved shoulder width is greater than 26 ft. Exceptions to the policy include noise issues, bicycle use, crash history, and other exceptions.

Annual average daily traffic (AADT) is a commonly utilized factor when determining the location of rumble strip installations. An analysis of rumble strips in North Dakota showed that the installation of rumble strips limited the proportional rise of crashes in areas with significantly higher AADT volumes in recent years (Kubas et al. 2013). In general, there is much variation in terms of the methods for selecting locations where rumble strips should be installed.

3. CRASH ANALYSIS

To assess the Iowa-specific effects of rumble strip installations, a data set was constructed for the two-lane primary highway network. It was necessary to analyze primary highways as opposed to secondary roadways due to limitations in available data. For the purposes of this study, only the two-lane undivided portion of the primary roadway network was considered. The two-lane undivided network was identified using the Iowa DOT's Geographic Information Management System (GIMS) Road Info file. Rumble strip installations were primarily determined through the use of the Safety Feature Inventory Tracking Database (SFITD), a file assembled based on the results of a recurring biennial survey of the primary roadway network that collects data for half of the primary network each year. Data for this particular study were reduced from the 2013 and 2014 surveys.

3.1 Data Description

Six types of rumble strip installations are identified in the SFITD: left continuous, left intermittent, center continuous, center intermittent, right continuous, and right intermittent. Figure 1 shows these six options in a screenshot of the tool used to create and reduce the SFITD.

Figure 1. Safety Feature Inventory Tracking Database interface showing six rumble strip installation options

These data were rigorously analyzed for quality by the research team. During the quality assurance (QA)/quality control (QC) process, several issues were identified, the first two of which pertain to the coding scheme used in the SFITD. First, the file does not differentiate between shoulder installations and edgeline installations. Therefore, in this analysis edgeline and shoulder rumble strips are aggregated together. The second issue is that the six installation categories are not used consistently across the database, making it difficult to distinguish between intermittent rumble strips and continuous rumble strips. Figure 2 provides an image of a roadway where both shoulders have the same type of rumble strip installation but where one side is coded as intermittent while the other is coded as continuous.

Figure 2. Right continuous with left intermittent

Figure 3 displays an image of an actual intermittent rumble strip installation. Note that a continuous rumble strip installation may contain some breaks (i.e., bicycle breaks). However, the intermittent installation is characterized by having more space without rumble strips than with. The Iowa DOT's standard road plan PV-12 generally was used for all projects except those segments with 14 ft Portland cement concrete (PCC) pavement lanes adjacent to granular shoulders, in which case standard road plan PV-11 was used. According to standard road plan PV-11, milled shoulder rumble strips should be installed with a gapped pattern on highways where bicyclists are legally commuting (Iowa DOT 2013).

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Figure 3. Intermittent rumble strip installation example

Figure 4 shows an example of a segment on IA 141 that includes continuous shoulder rumble strips with bicycle gaps, which was incorrectly classified as having intermittent rumble strips.

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Figure 4. Continuous rumble strip installation with bicycle gaps

Another issue with the SFITD involves intermittent rumble strips being mistakenly identified at locations where gaps in the rumble strip installation are provided to accommodate driveways.

Figure 5 (top) shows an aerial image of a stretch of roadway that has been coded as having left and right intermittent rumble strips. However, the intermittent term appears to only indicate that driveway breaks are present. Figure 4 (bottom) shows an example of a segment on US 169 with continuous shoulder rumble strips, with gaps provided at driveways, where this misclassification issue was identified.

Figure 5. Rumble strip installation with gaps at driveways

A final issue regarding the quality of the SFITD is completeness. Figure 6 illustrates a stretch of roadway that was identified as having only a centerline installation. However, Google Street View clearly illustrates that rumble strips have been installed on both the shoulder and the centerline.

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Figure 6. Roadway where shoulder rumble strips were not identified in SFITD

In general, the vast majority of centerline rumble strip installations throughout Iowa have been done in combination with shoulder or edgeline rumble strips. This is one issue that was investigated specifically as a part of the QA/QC process. Figure 7 shows one of the few examples of centerline-only installations along US 6 between Wapello and Grandview.

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Figure 7. Centerline-only installation example

To address various types of data quality issues regarding rumble strip installation locations, data were combined with information from the Iowa DOT Highway Safety Improvement Program (HSIP) project list and the GIMS Direct Lane file to minimize gaps in rumble strip information from the SFITD due to the biennial nature of the data collection process. Figure 8 illustrates the location of rumble strip installations across Iowa based on records from the HSIP.

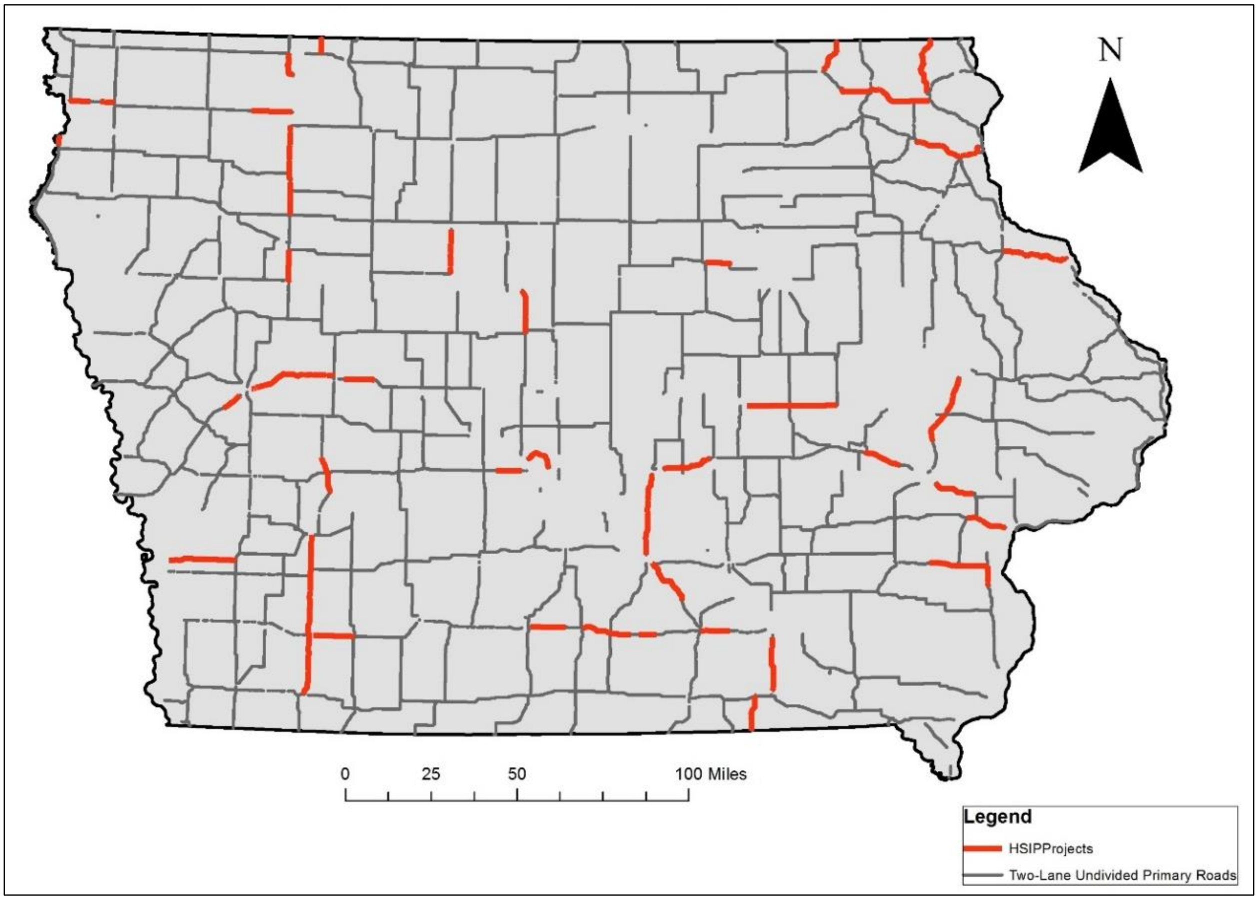


Figure 8. Rumble strip installation locations from the Highway Safety Improvement Program

As an additional means of quality assurance/quality control (QA/QC), Google Earth imagery was used to the extent possible to assess whether the data furnished by the Iowa DOT were accurate and, in some cases, to identify additional rumble strip installations. The result of the collection of rumble strip location data and the QA/QC process was a georeferenced file identifying all known rumble strip installations by category (centerline only, edgeline or shoulder only, both centerline and edgeline/shoulder) on the two-lane undivided primary road network in the state of Iowa. Figure 9 illustrates the rumble strip installation locations in the state.

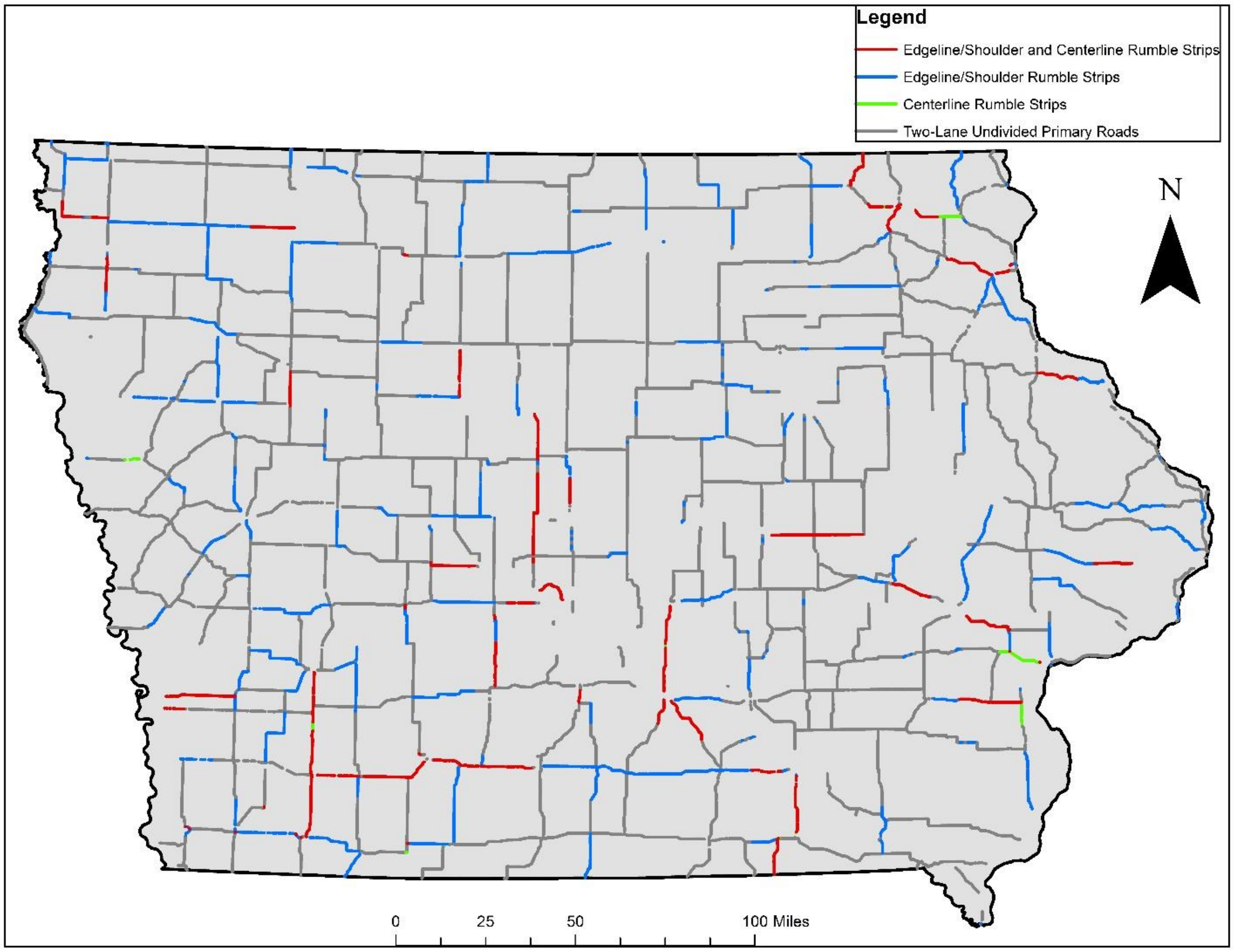


Figure 9. Iowa two-lane undivided primary roadway rumble strip installation locations

Using the completed rumble strip installation database, the GIMS roadway segments were divided into analysis segments such that only one type of rumble strip installation (shoulder/edgeline, centerline, both, or none) was present on a given segment. The GIMS database was also utilized to obtain traffic volume data and lane width data (derived from the GIMS surface width field). Shoulder type and width information was collected using the SFITD file.

Police-reported crash data were identified from the statewide crash database maintained by the Iowa DOT for the years 2014 and 2015. These years were chosen due to the availability and completeness of data pertaining to rumble strip locations. A subset of crashes was identified as "target crashes," i.e., crash types that would potentially be affected by the presence of rumble strips. This subset was then split into two types of target crashes, edge crashes and centerline crashes, each of which includes multiple subcategories, which are documented in Table 3.

Table 3. Statewide crashes on two-lane, undivided primary highways

Crash Type	Severity					
	Total	K	A	B	C	PDO
Total Crashes	10,162	110	398	1,011	1,344	7,299
Total Target	3,226	76	237	534	573	1,806
Edgeline Target	1,433	23	93	235	295	787
SV, ROR-Right, FO	765	11	53	136	158	407
SV, ROR-Right, No FO	326	10	28	60	79	149
SV, ROR-Straight/Right, FO	64	0	3	7	11	43
SV, ROR-Straight/Right, No FO	13	0	2	3	0	8
SV, No ROR, No XCL, FO	265	2	7	29	47	180
Centerline Target	1,793	53	144	299	278	1,019
SV, ROR-Left, FO	326	1	25	65	54	181
SV, ROR-Left, No FO	120	2	9	32	26	51
SV, ROR-Straight/Left, FO	1	0	0	0	0	1
SV, ROR-Straight/Left, No FO	0	0	0	0	0	0
SV, XCL, FO	183	4	13	36	33	97
SV, XCL, No FO	51	1	4	14	12	20
MV, Head-on	269	37	57	64	54	57
MV, Sideswipe-same	499	1	13	36	51	398
MV, Sideswipe-opposite	344	7	23	52	48	214

SV = Single vehicle, MV = Multi-vehicle, ROR = Run-off-road, FO = Fixed object, XCL = Cross centerline
K = Fatality, A = Disabling Injury, B = Evident Injury, C = Possible Injury, PDO = Property Damage Only

Single-vehicle target crashes were identified using the sequence of events reported in the crash data, while multiple-vehicle target crashes were identified using the manner of collision field. It is worth noting that given that the single-vehicle target crashes were identified by the sequence of events, an individual single-vehicle crash could be involved in multiple event types (e.g., a vehicle left the road *and* struck a fixed object). However, the crash is only accounted for once in the data set. The specific subcategory for a given single-vehicle crash was determined using the order of the sequence of events, e.g., if a vehicle ran off the road to the right, then re-entered and ran off the road to the left, the crash was categorized as a run-off-road-right crash. The described categorization methodology ultimately resulted in some ambiguity for two types of crashes. First, not all single-vehicle fixed object crashes were coded as having departed the road. In such cases, the crash was examined to determine if the centerline was crossed, in which case the crash was identified as a centerline target crash; otherwise, the crash was coded as an edgeline target crash. The second type of crash that proved difficult to classify was the run-off-road-straight crash, a crash type where the vehicle continues to travel straight instead of properly navigating a curve. Similar to the classification of the non-run-off-road fixed object crashes, these crashes were considered edgeline crashes unless the sequence of events indicated that the centerline was crossed.

Table 3 shows that out of 10,162 crashes on the two-lane, undivided primary highway network, over 30% were of a type that could be impacted by the installation of rumble strips. Prior to conducting a statistical analysis, data visualization techniques were used to identify underlying trends in the data. The results of the data visualization allowed the research team to appropriately identify roadway characteristics that contribute to crashes that could ultimately be affected by the installation of rumble strips.

As was expected, most of the two-lane, undivided primary highway network has a posted speed limit of 55 miles per hour. Given that rumble strips are generally used in rural areas and the standard practice of the Iowa DOT is to only install rumble strips at locations where the posted speed limit is 50 miles per hour or greater (Iowa DOT 2016), the overwhelming majority of installations occur on roadways where the speed limit is posted at 55 miles per hour. Due to this fact, it is difficult to ascertain the effects of rumble strip use at speed limits other than 55 miles per hour. Furthermore, centerline-only rumble strip installations (i.e., without shoulder or edgeline rumble strips) are also minimal in the state of Iowa.

In the modeling of count data, such as crashes, it is necessary to include an exposure term in the data. In the case of traffic crashes, traffic volume and segment length are commonly used as exposure measures. Segment length is frequently considered in statistical models as an offset variable, where the correlation between length and crashes is assumed to be one to one. The one-to-one relationship lends itself to interpreting results in terms of crashes per mile. Figure 7 illustrates the relationship between traffic volume and crashes per mile versus rumble strip installation type by plotting logarithmic best fit lines for each of the three installation types.

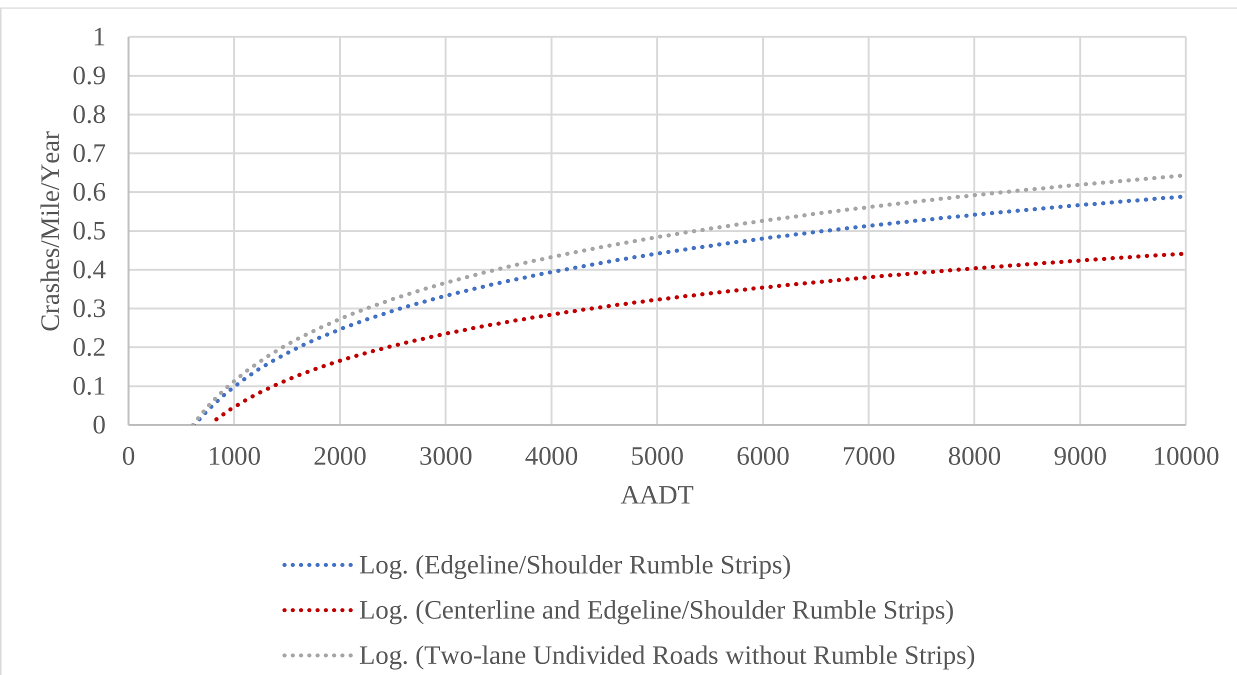


Figure 10. Best fit lines, traffic volume versus crashes, by rumble strip installation type

The creation of the analysis data set resulted in the identification of two significant issues. First, due to the data reduction process, many extremely short segments were created. These short segments were problematic in that they tended to inflate per mile crash rates. In order to prevent this from happening, the data set used for this analysis was restricted only to segments that were at least 0.1 miles long. The second issue identified was that very few instances of centerline-only rumble strip installations are present within the state of Iowa. Due to this issue, the final statistical models consider the combination of centerline and shoulder/edgeline rumble strips as well as those sites that have only shoulder or edgeline rumble strips. Descriptive statistics for the analysis segments can be found in Table 4.

Table 4. Descriptive statistics of analysis segments

Characteristic	Min	Max	Average	Std. Dev.	Count
Segment Length (miles)	0.10	2.44	0.39	0.28	27,896
Annual Average Daily Traffic	10	17700	2428.22	1468.24	27,896
Truck Percentage	2.00	45.00	15.00	6.00	27,896
Centerline Rumble Strips	0	1	0.08	0.27	2,222
Edge/Shoulder Rumble Strips	0	1	0.27	0.44	7,438
Located in City	0	1	0.11	0.31	3,082
Located in Incorporated area	0	1	0.02	0.14	576
Located in Urban Area	0	1	0.04	0.21	1,120
Paved Shoulder Width	0	12	0.95	1.90	27,896
Paved Shoulder Width over 2 ft	0	1	0.07	0.25	1,874
Non-paved Shoulder Width	0	12	4.29	3.89	27,896
Non-paved Shoulder Width over 4 ft	0	1	0.46	0.5	12,914
Lane Width	9	15	11.95	0.62	27,896
Lane Width less than 12 ft	0	1	0.14	0.34	3,832
Lane Width greater than or equal to 12 ft	0	1	0.86	0.34	24,064
Speed Limit	15	55	53.14	5.67	27,896
Speed Limit less than 55 MPH	0	1	0.12	0.33	3,402
Speed Limit equal to 55 MPH	0	1	0.88	0.33	24,494
Edgeline Target Crashes	0	3	0.04	0.20	1,022
Centerline Target Crashes	0	4	0.04	0.22	1,254
Total Target Crashes	0	6	0.08	0.31	2,276
Observations (Segment-Years)					27,896

3.2 Statistical Methodology

After examining the general relationships between crashes and traffic volume for each of the rumble strip installation scenarios, a series of crash prediction models, commonly referred to as safety performance functions (SPFs), were estimated to examine the effect of rumble strips, as well as roadway geometric, operational, and geographic characteristics, on the safety performance of the two-lane undivided roadway network. Because crash data are comprised of non-negative integers, traditional regression techniques (e.g., ordinary least squares) are generally not appropriate. Given the nature of such data, a Poisson distribution has been shown to provide a better fit and has been used widely to model crash frequency data. In the Poisson model, the probability of an analysis segment *i* experiencing y_i crashes during a one-year period is given by the following:

$$P(y_i) = \frac{EXP(-\lambda_i)\lambda_i^{y_i}}{y_i!} \quad (1)$$

where:

- $P(y_i)$ is the probability of analysis segment *i* experiencing y_i crashes
- λ_i is the Poisson parameter for analysis segment *i*, which is equal to the segment's expected number of crashes per year, $E[y_i]$

Poisson models are estimated by specifying the Poisson parameter λ_i (the expected number of crashes per period) as a function of explanatory variables, the most common functional form being $\lambda_i = \exp(\beta X_i)$, where X_i is a vector of explanatory variables and β is a vector of estimable parameters.

A limitation of this model is the underlying assumption of the Poisson distribution that the variance is equal to the mean. As such, the model cannot handle overdispersion, wherein the variance is greater than the mean. Overdispersion is common in crash data and may be caused by data clustering, unaccounted temporal correlation, model misspecification, or ultimately by the nature of the crash data, which are the product of Bernoulli trials with an unequal probability of events (Lord 2006). Overdispersion is generally accommodated through the use of negative binomial models (also referred to as Poisson-gamma models).

The negative binomial model is derived by rewriting the Poisson parameter for each segment as $\lambda_i = \exp(\beta X_i + \varepsilon_i)$, where $EXP(\varepsilon_i)$ is a gamma-distributed error term with mean 1 and variance α. The addition of this term allows the variance to differ from the mean as $VAR[y_i] = E[y_i] + \alpha E[y_i]^2$. The negative binomial model is preferred over the Poisson model because the latter cannot handle overdispersion and, as such, may lead to biased parameter estimates (Lord and Park 2008).

If the overdispersion parameter (α) is equal to zero, the negative binomial reduces to the Poisson model. Estimation of λ_i can be conducted through standard maximum likelihood procedures. While alternatives to the negative binomial model framework exist (e.g., the Conway-Maxwell model), the negative binomial model remains the standard in SPF development.

The goodness of fit for an SPF has been shown to vary when it is applied to a different set of roadway data than that from which the SPF was originally derived. In these situations, a calibration procedure can be utilized to adjust the predicted number of crashes. This calibration factor is equal to the ratio of the number of crashes observed on the network to the number of crashes predicted by the SPF (AASHTO 2010). The predicted number of crashes for each road segment is multiplied by the calibration factor, which results in improved precision when applying the SPF to a new data set. The EB method can then be used to provide a weighted estimate of the number of crashes that are expected to occur at a specific site. This EB estimate can be used to prioritize segments for rumble strip installation based on the number of target (i.e., lane departure) crashes that are expected to occur in the future.

3.3 Analysis Results

The SPFs developed for the two-lane, undivided primary highway system in Iowa are summarized in Table 5, Table 6, and Table 7.

Table 5. SPF results – total target crashes

Parameter	Estimate	Std. Error	z value	Pr(>|z|)
Intercept	-9.127	0.332	-27.458	2.00E-16
Natural Log of AADT	1.000	0.043	23.440	2.00E-16
Centerline rumble strips	-0.265	0.093	-2.855	0.0043
Edgeline/shoulder rumble strips	-0.108	0.056	-1.944	0.0519
2 ft paved/4 ft non-paved shoulder	-0.237	0.044	-5.340	9.30E-08
Lane width less than 12 feet	0.418	0.070	6.013	1.82E-09
Overdispersion Parameter	0.956	0.130		

Table 6. SPF results – edgeline target crashes

Parameter	Estimate	Std. Error	z value	Pr(>|z|)
Intercept	-7.583	0.478	-15.870	2.00E-16
Natural Log of AADT	0.700	0.062	11.315	2.00E-16
Edgeline/shoulder rumble strips	-0.175	0.077	-2.280	0.0226
2 ft paved/4 ft non-paved shoulder	-0.296	0.065	-4.569	4.90E-06
Lane width less than 12 feet	0.489	0.095	5.169	2.35E-07
Overdispersion Parameter	1.287	0.324		

Table 7. SPF results – centerline target crashes

Parameter	Estimate	Std. Error	z value	Pr(>|z|)
Intercept	-11.604	0.439	-26.462	2.00E-16
Natural Log of AADT	1.234	0.055	22.230	2.00E-16
Centerline rumble strips	-0.404	0.110	-3.682	0.000231
2 ft paved/4 ft non-paved shoulder	-0.176	0.058	-3.030	0.002444
Lane width less than 12 feet	0.343	0.098	3.500	0.000465
Overdispersion Parameter	0.926	0.204		

The SPFs were developed with the intention of evaluating the relationship between lane departure crashes and the presence (or absence) of rumble strips. Each rumble strip type was considered using a binary indicator variable. Various roadway geometric details were analyzed using a series of binary indicator variables as well. Ultimately, three models were developed to demonstrate the effectiveness of rumble strips at reducing specific types of crashes.

Table 5 presents the results of an SPF that was estimated by considering rumble strips by location versus the number of all "target crashes" on a given road segment. In this model, both centerline rumble strips and edgeline/shoulder rumble strips were examined simultaneously. The SPFs estimated by considering the effect of edgeline rumble strips on reducing edgeline-related crashes are shown in Table 6, while the effect of centerline rumble strips on reducing centerline-related crashes is documented in Table 7. It should be noted the presence of centerline rumble strips was considered as a predictor in the analysis of edgeline target crashes and the presence of edgeline rumble strips was considered in the analysis of centerline target crashes. This was done to address a potential concern that edgeline rumble strips may increase the frequency of cross-centerline target crashes due to drivers shifting their lane position toward the centerline (and likewise with centerline rumble strips potentially increasing edgeline target crashes). However, neither of these variables was found to be statistically significant. This is important as it suggests edgeline and centerline rumble strips reduce the frequency of their intended target crashes, but do not increase the frequency of the other type of target crashes. Graphical representations of each of the three SPFs are illustrated in Figure 11, Figure 12, and Figure 13.

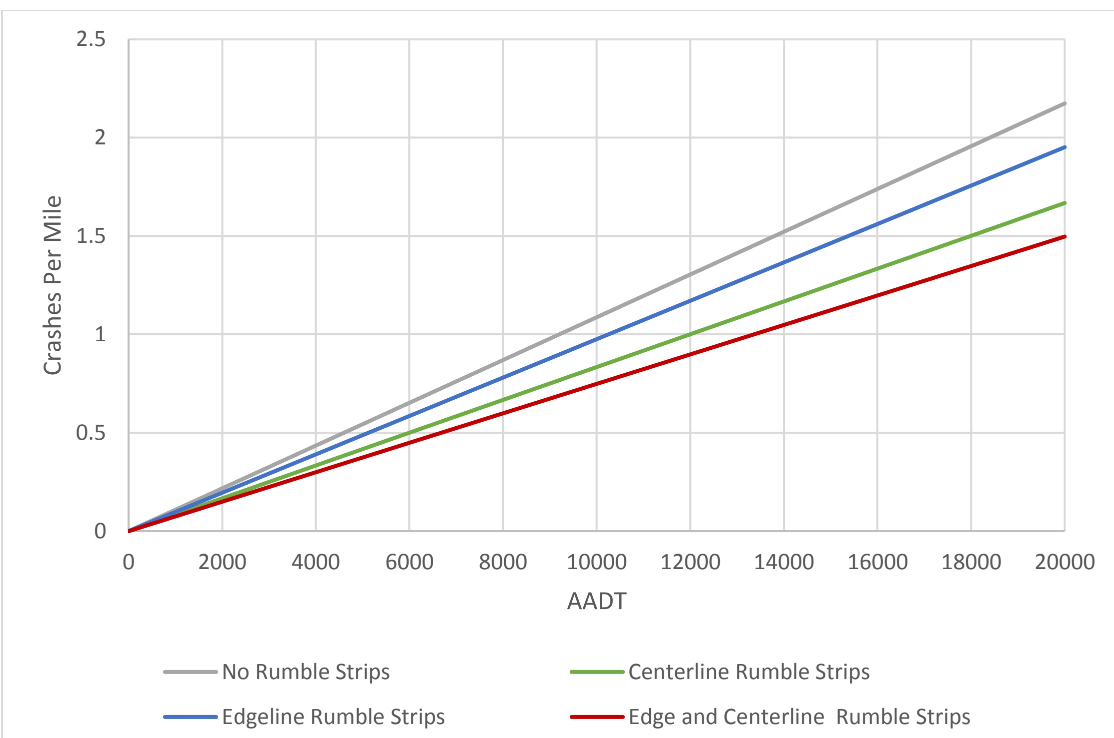


Figure 11. Graphical representation of SPF for all target crashes

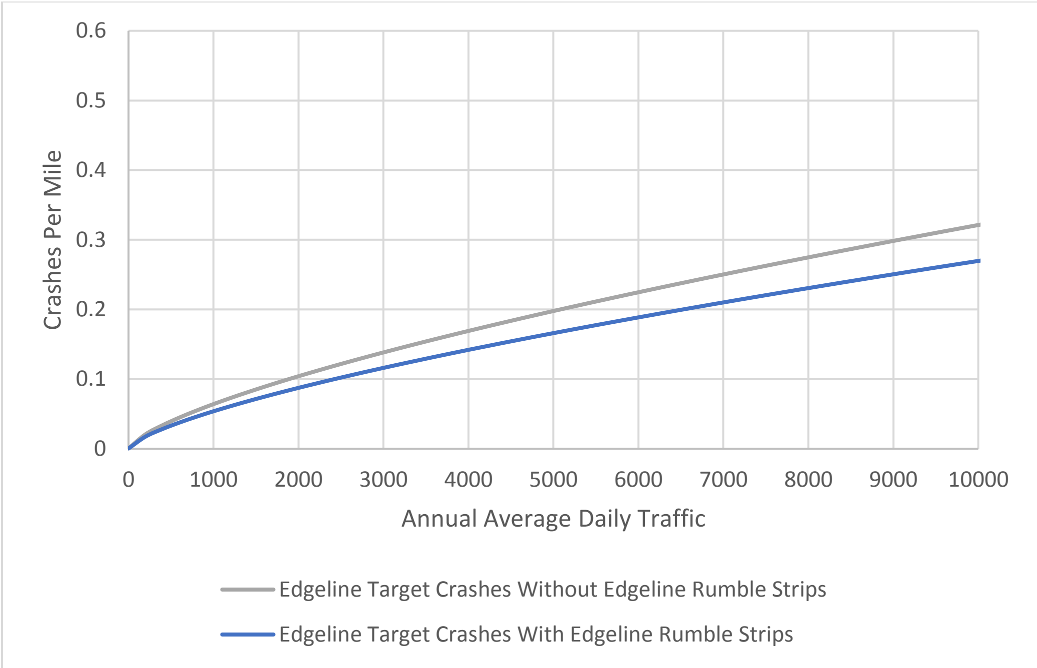


Figure 12. Graphical representation of SPF for edgeline target crashes

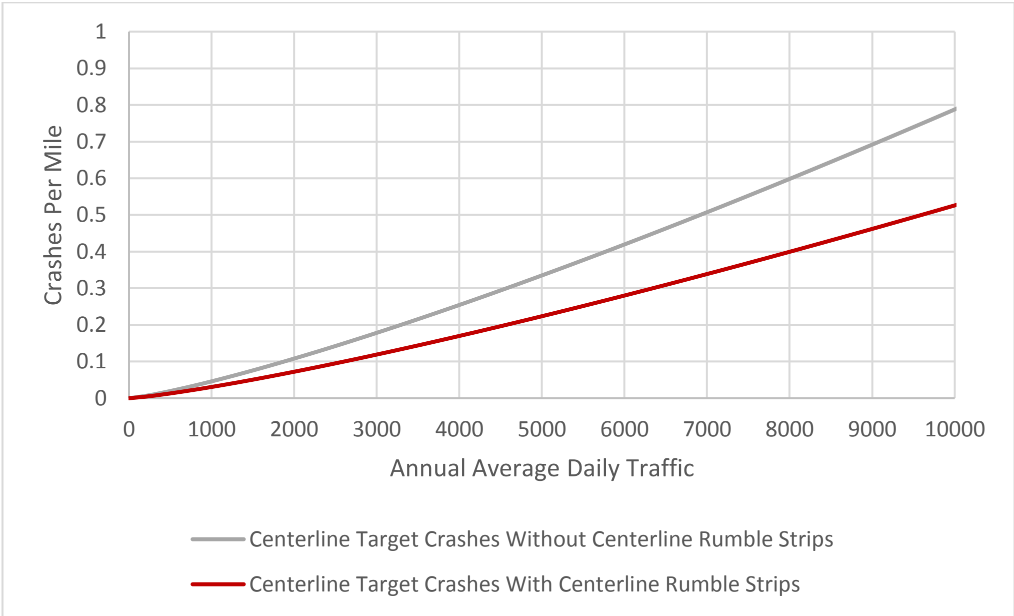


Figure 13. Graphical representation of SPF for centerline target crashes

3.4 Discussion

3.4.1 Interpretation of SPFs

The general relationships between crashes and traffic volumes, regardless of whether rumble strips are installed, are summarized in Figure 14.

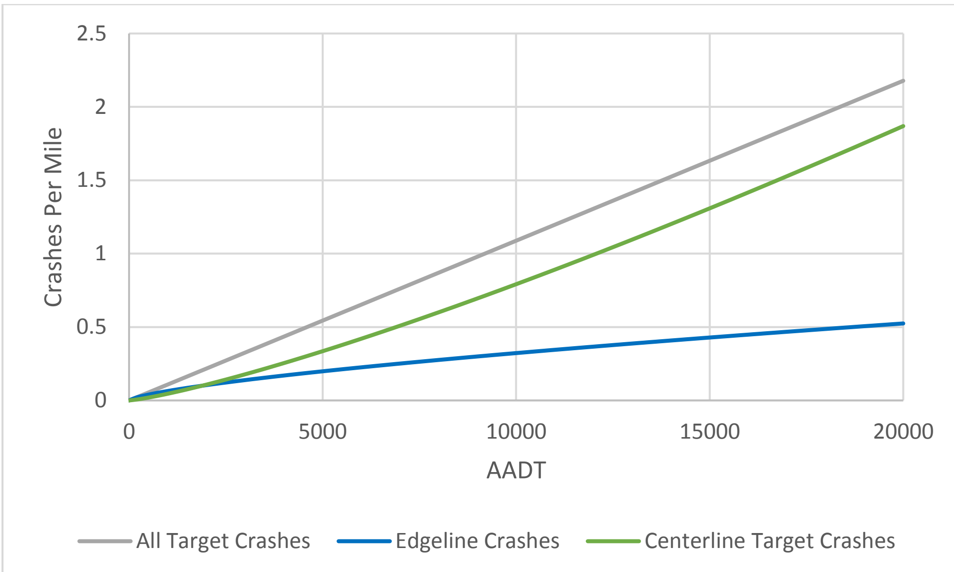


Figure 14. Target crashes by type and AADT

When considering all types of target crashes, the predicted crash rate per mile increases nearly linearly with traffic volume. The predicted edgeline crash rate also increases with traffic volume. However, as traffic volume increases, the rate of expected edgeline crashes increases at a lower rate. For centerline crashes, the predicted crash rate increases consistently as traffic volume increases.

When the rumble strip types were considered simultaneously, both centerline and edgeline/shoulder rumble strips were found to be associated with lower crash rates. When each of the rumble strip types (and corresponding target crash types) was considered separately, segments with centerline rumble strips experienced 33.2% fewer centerline-related crashes while being associated with a negligible impact on edgeline crashes. Similarly, segments with edgeline/shoulder rumble strips experienced 16.1% fewer edgeline-related crashes while being associated with a negligible impact on centerline crashes. The most effective rumble strip installation scenario for improving traffic safety on the two-lane, undivided network was found to be centerline and edgeline or shoulder rumble strips in combination. In light of the two models, it appears that installing centerline rumble strips with edgeline or shoulder rumble strips provides an additive improvement to road safety. This result makes sense intuitively, considering that each installation type addresses a specific subset of crashes (e.g., centerline rumble strips reduce crashes where the centerline is crossed, while edgeline and shoulder rumble strips reduce crashes where a vehicle departs the roadway).

The effect of roadway geometry elements on crash frequency was found to be consistent across each of the three SPFs. Lane width and shoulder width were included in the model initially as a series of separate binary indicators. Lane widths and shoulder widths that were found to perform similarly were ultimately combined. The results of this process indicated that sites with paved shoulders over 2 ft wide experienced fewer crashes, while locations with non-paved shoulders over 4 ft wide also experienced fewer crashes. The effect of lane width on the target crashes yielded an expected result, in that drivers would logically be expected to cross the centerline or run off of the road more frequently when narrower lanes are present. The presence of shoulders (paved shoulders over 2 ft wide and non-paved shoulders over 4 ft wide) was shown to be associated with increased roadway safety. From an intuitive standpoint, it makes sense that the safety benefit of a shoulder would be realized at a narrower width for paved shoulders versus non-paved shoulders, because road users would likely be more inclined to use a paved shoulder than a non-paved shoulder to avoid a collision or to recover from crossing the edgeline.

3.4.2 Application of SPFs to the Secondary Network

The results of this cross-sectional analysis indicate that rumble strips are effective at reducing the frequency of run-off-road, head-on, sideswipe, and fixed object collisions on the two-way, undivided roadway network. While the SPFs estimated in this study were based specifically on the primary roadway network, the results are broadly applicable to most two-lane undivided roadways. In order to provide the Iowa DOT and county road agencies with details as to where the installation of rumble strips is likely to be most beneficial, the expected crash rates and crash frequencies were calculated for every paved secondary roadway in the state of Iowa using the SPFs. Prior to applying the SPFs to the secondary network, it was necessary to investigate some of the network's basic characteristics. Descriptive statistics regarding the secondary network, with crashes given over a five-year average (2011–2015) are shown in Table 8.

Table 8. Secondary network descriptive statistics

Characteristic	Average	Min	Max	Std Dev	Count
Segment length (miles)	0.44	0.001	2.124	0.36	43,504
Annual average daily traffic (AADT)	725.87	1	31,900	1,006.95	43,504
2 ft paved or 4 ft non-paved shoulder	0.19	0	1	0.39	8,146
Lane width less than 12 feet	0.64	0	1	0.48	27,890
Edgeline target crashes per year	0.04	0	2.4	0.11	1,553.2
Centerline target crashes per year	0.03	0	1.8	0.09	1,272
Total target crashes per year	0.06	0	3.8	0.15	28,252
Number of observations (segments)					43,504

On average, roadway segments on the secondary network serve much lower traffic volumes than those on the primary network. Therefore, in order to accurately estimate the expected crash frequencies on this network, the SPFs were calibrated by creating a ratio of the total predicted crash values estimated by applying the SPFs to the values actually observed on the secondary network. The calibration of the SPFs developed on the primary network to the secondary network maintains the Iowa-specific effect of rumble strips on roadway safety while accounting for the differing performance between the two roadway classifications. The results of the calibration for each of the SPFs are given in Table 9.

Table 9. Calibration factors for the secondary network

SPF	Total Observed Crashes	Total Predicted Crashes	Calibration Factor
Total Target Crashes	2,825.40	1,600.60	1.77
Centerline Crashes	1,272.20	640.28	1.99
Edgeline Crashes	1,553.20	1,073.76	1.45

Following the calibration procedure, two sets of estimates were developed using the SPFs. First, the expected numbers and rates (per mile) of target crashes were calculated for the entire secondary network. These estimates were developed using the previously described empirical Bayes methodology, which provides a weighted estimate based on the predicted and observed number of crashes experienced on each segment. Second, estimates were developed to assess the expected reduction in crashes that would occur if rumble strips were installed across the entire secondary network. The resulting estimates are shown in Table 10 and Table 11. These projections illustrate the potential per year reduction in crash frequency and rate if rumble strips were to be applied across the entirety of the secondary network.

Table 10. Projected crash frequency per year

	Expected Crashes Per Year		
Crash Type	**No Rumble Strips**	**With Rumble Strips**	**Percent Reduction**
Total Target Crashes	2,760.658	1,982.222	28.2
Centerline Crashes	1,248.361	855.967	31.4
Edgeline Crashes	1,539.217	1,305.692	15.2

Table 11. Projected crash rate per mile per year

	Expected Crash Rate Per Mile Per Year		
Crash Type	**No Rumble Strips**	**With Rumble Strips**	**Percent Reduction**
Total Target Crashes	0.164	0.116	29.2
Centerline Crashes	0.080	0.055	31.9
Edgeline Crashes	0.083	0.071	15.2

These results show that the network-wide installation of rumble strips would be expected to produce a substantial improvement in roadway safety. However, given resource constraints, county road agencies must discern candidate locations that would provide the greatest potential for crash reductions. To this end, the secondary system was stratified into three groups based on the relative risk of edgeline- and centerline-related crashes. The stratification was done using the Jenks method in ArcGIS, a form of clustering that maximizes the differences between classes and divides classes where there are relatively large differences in values (ESRI 2016). The classification schemes that resulted from the application of the Jenks method therefore group the road segments based on sites that have similar expected crash rates and frequencies. Figure 15, Figure 16, and Figure 17 display the paved secondary roadway network in Iowa stratified by crash rate for each of the various crash types. In each of the maps, the green roadway segments represent the sites with the lowest expected crash rates, yellow segments represent the sites that fall into an intermediate class, and red segments represent roadways with the highest expected crash rates. Chapter 6 provides guidelines to aid in the implementation of rumble strips on the county system based upon the results of this safety analysis.

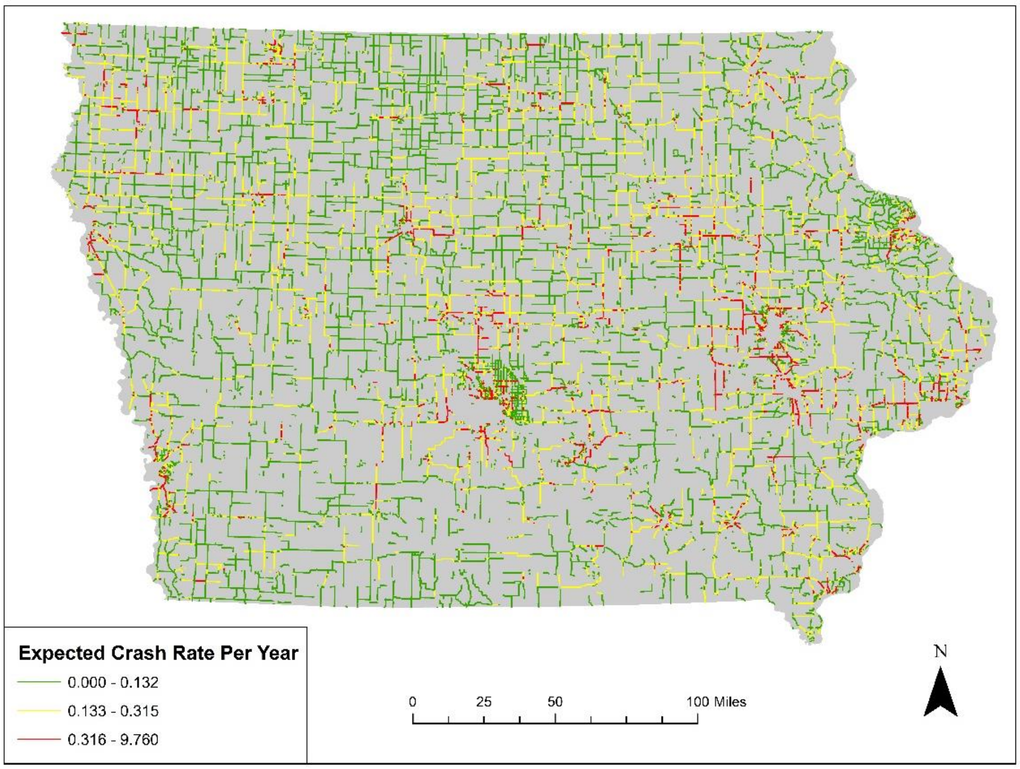


Figure 15. Expected centerline- and edgeline-related crashes per mile per year

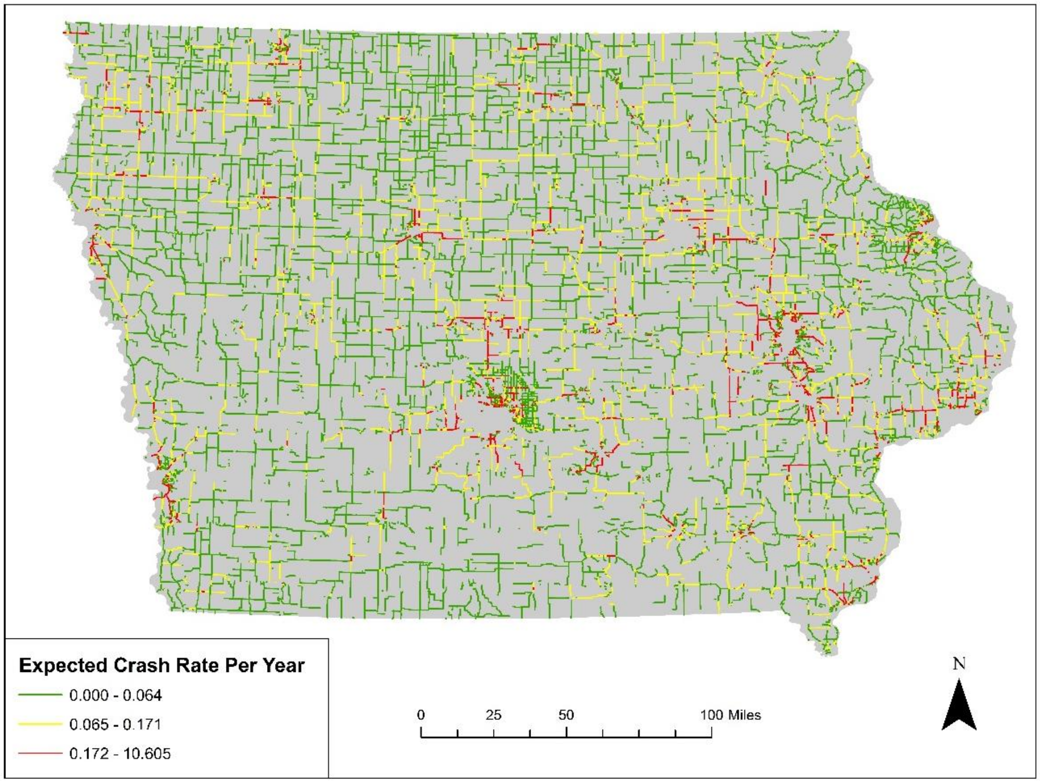


Figure 16. Expected centerline-related crashes per mile per year

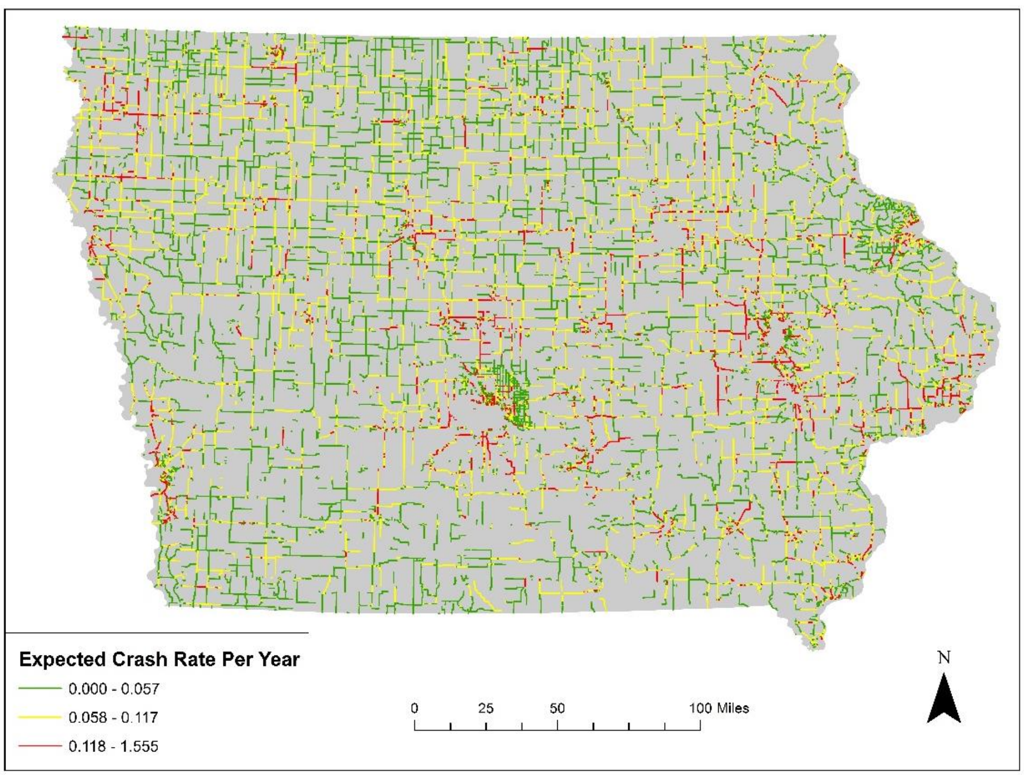


Figure 17. Expected edgeline-related crashes per mile per year

County road agencies may wish to look at the expected crash frequency in addition to the crash rate. To this end, Figure 18, Figure 19, and Figure 20 display the expected crash frequencies of the paved secondary road segments. Ultimately, these maps provide information regarding the locations where rumble strips could potentially have the largest impact.

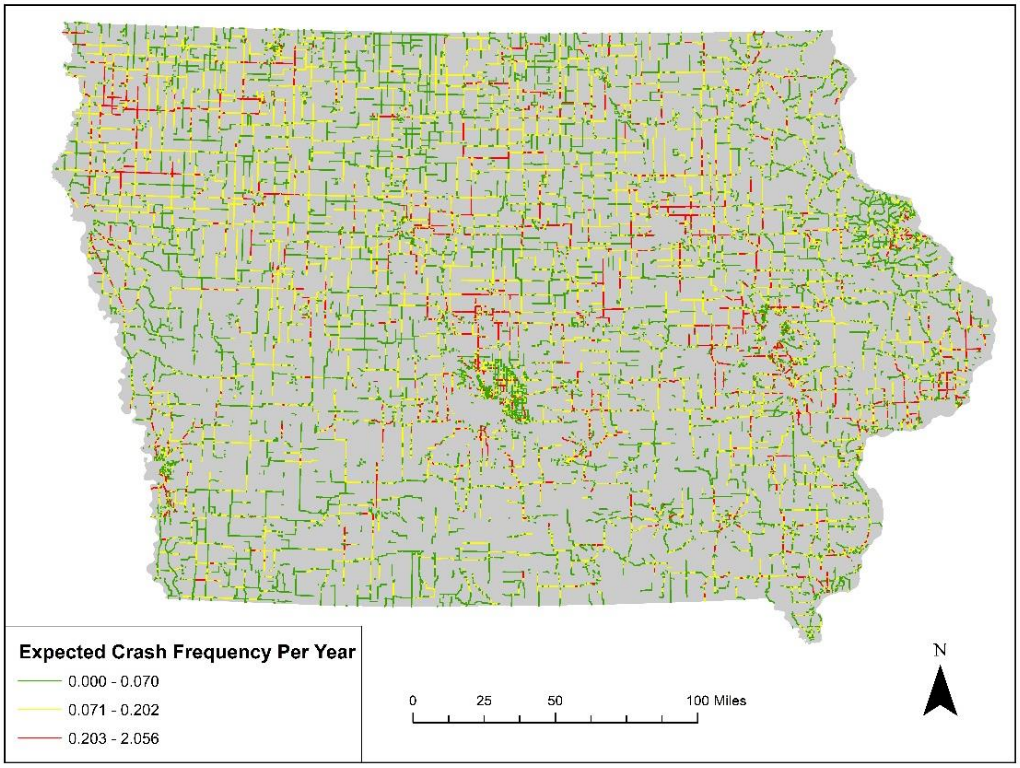


Figure 18. Expected edgeline- and centerline-related crashes per year

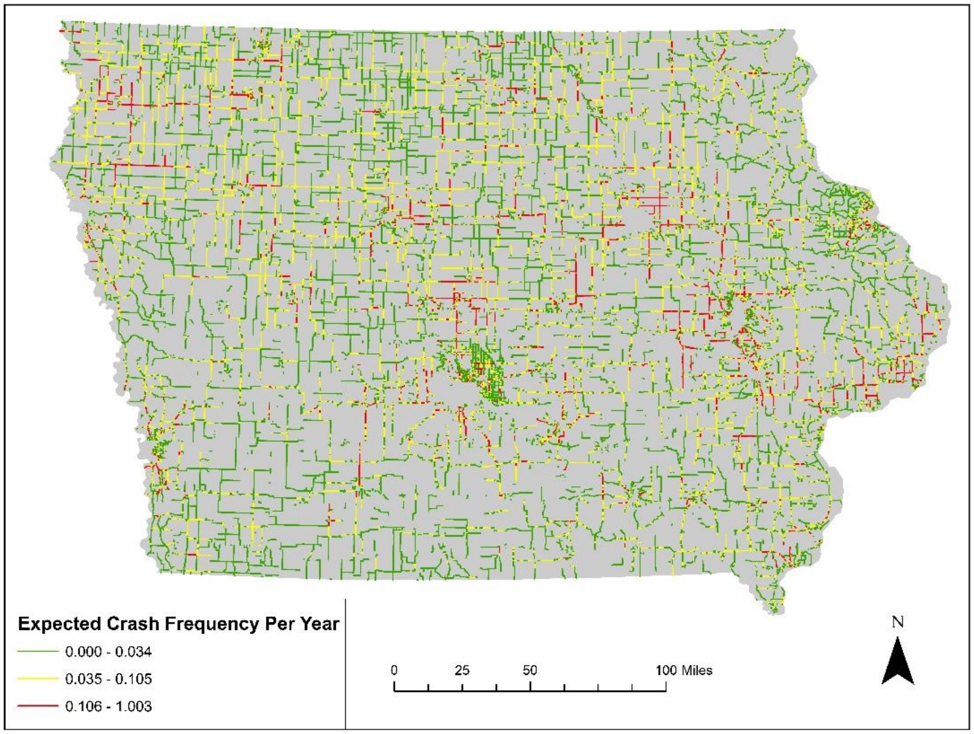


Figure 19. Expected centerline-related crashes per year

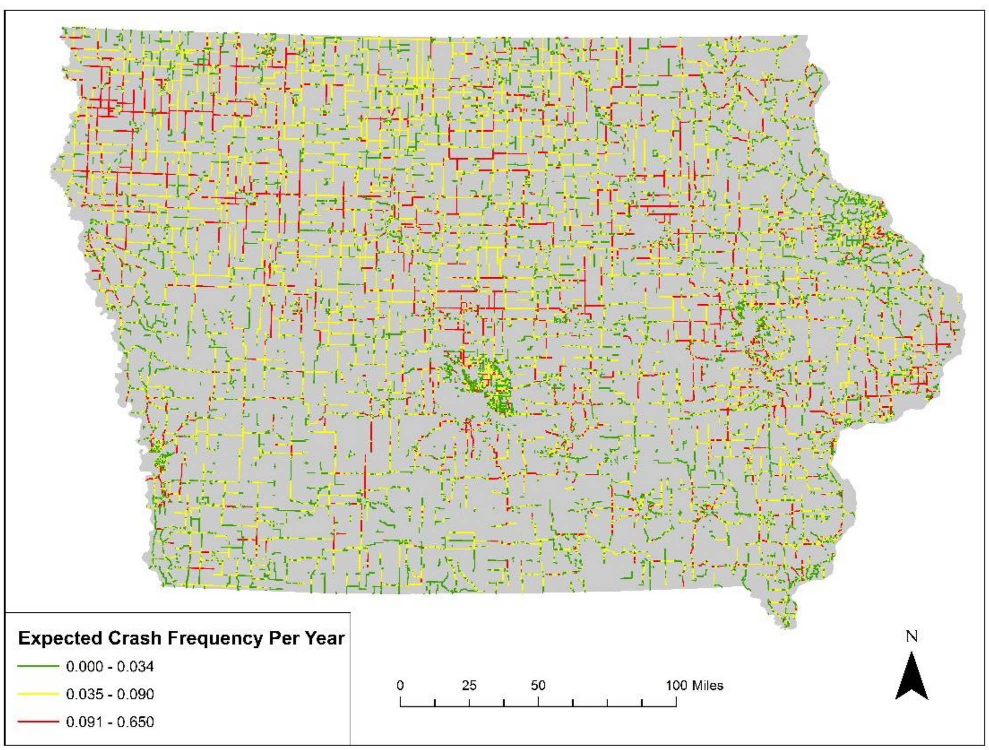


Figure 20. Expected edgeline-related crashes per year

4. FIELD STUDIES OF DRIVER BEHAVIOR

While the preceding crash analysis documents the effectiveness of centerline rumble strips and shoulder rumble strips in reducing crashes, a related question of interest is how frequently incidental contact occurs when a motorist is driving through a road segment that has some combination of CLRS and SRS (or ELRS).

Data were collected pertaining to various roadway geometric dimensions and vehicular interactions with rumble strips on rural two-lane highway sections at 53 locations within 14 Iowa counties. The counties were as follows:

- Adair
- Adams
- Buchanan
- Cass
- Cedar
- Clinton
- Dallas
- Hamilton
- Jasper
- Madison
- Marion
- Marshall
- Polk
- Story

A site summary of each data collection location is included in Appendix A.

Roadway geometry information and rumble strip dimensions were manually collected at each site by a data collection team. Motorist interactions with the SRS and/or CLRS were collected by a data collection trailer, which consisted of a video camera and Wavetronix radar sensor. The data collection trailer was located away from the roadside in the nearest available right of way. The data collection trailer was left at each location for a minimum of eight daylight hours. The data collection team attempted to obtain a minimum of 1,000 vehicular passes to ensure that an adequate sample of motorists was collected at each location. To ensure extensive coverage of all existing rumble strip installation scenarios, data were collected along tangents and curves with various types of SRS and/or CLRS installation combinations. Control data were also collected on both tangents and curves where no rumble strips were present. The frequency of data collection for each roadway and rumble strip combination is displayed in Table 12.

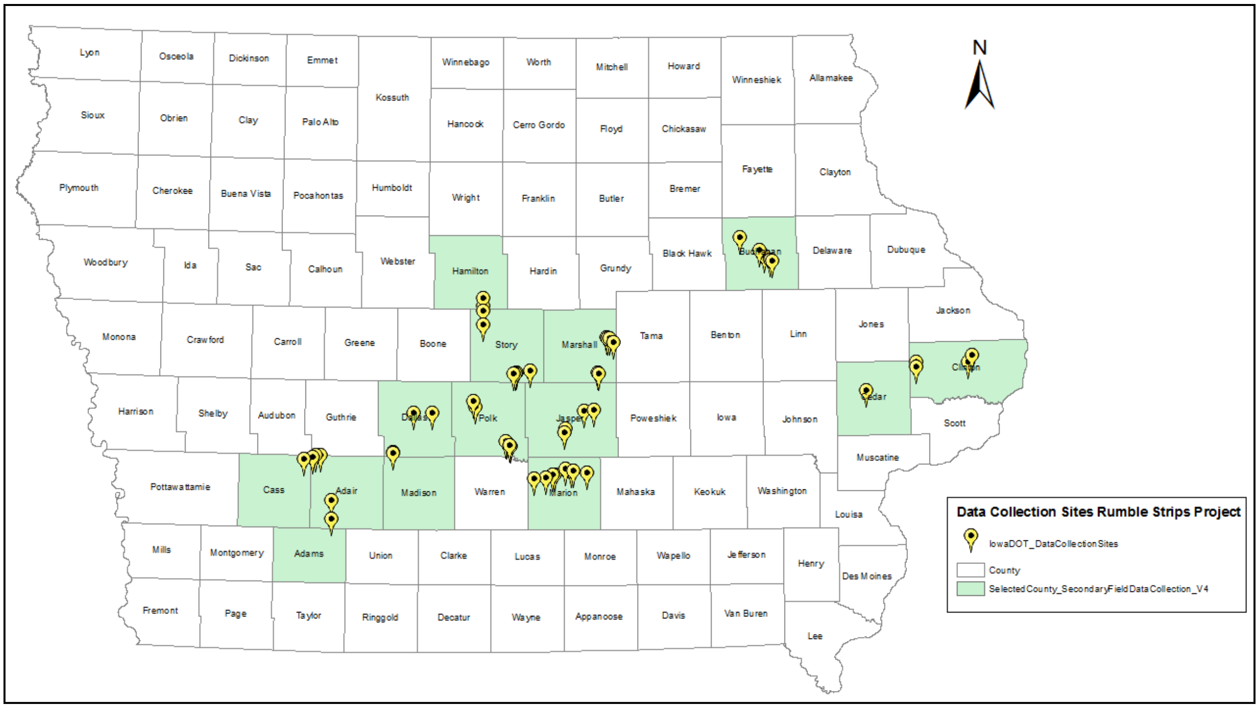


Figure 21. Data collection sites for field studies of driver behavior in Iowa, 2016

Table 12. Data collection combination frequency

Site Type	Count	Description
Tangent Control	9	Tangential highway segment without rumble strips
Curve Control	4	Curved highway segment without rumble strips
Tangent EL	5	Tangential highway segment with ELRS along both edgelines
Curve EL	6	Curved highway segment with ELRS along both edgelines
Tangent 1 EL	0	Tangential highway segment with ELRS along one edgeline
Curve 1 EL	1	Curved highway segment with ELRS along one edgeline
Tangent 1 EL CLRS	1	Tangential highway segment with ELRS along one edgeline and CLRS
Curve 1 EL CLRS	0	Curved highway segment with ELRS along one edgeline and CLRS
Tangent Both SRS and CLRS	4	Tangential highway segment with ELRS along both edgelines and CLRS
Curve Both SRS and CLRS	4	Curved highway segment with ELRS along both edgelines and CLRS
Tangent CLRS	2	Tangential highway segment with CLRS
Curve CLRS	2	Curved highway segment with CLRS
Tangent SRS	8	Tangential highway segment with SRS along both shoulders
Curve SRS	7	Curved highway segment with SRS along both shoulders

4.1 Site Selection

At the outset of the study, limited information was available as to the location of rumble strips on the secondary highway system. Consequently, a survey was distributed to county engineers in all 99 Iowa counties to determine basic roadway geometric information, rumble strip configurations, and the location of rumble strip installations within each respective county. Basic geometric information consisted of variables such as the lane width and shoulder width of the installation roadway. Of the 99 counties that were contacted, 67 counties responded to the survey. Among the responding counties, 48 did not have any rumble strip installations, while 19 counties provided updated information regarding the installation locations of SRS and/or CLRS on the secondary highway system within their county. The recorded responses from the county engineers are aggregated in Table 13.

Table 13. Rumble strip installations on secondary highway system

County	Roadway	Length (miles)	Lane Width (ft)	Paved Shoulder Width (ft)	Total Shoulder Width (ft)	Rumble Strip Type	CLRS Length (in.)	SRS Length (in.)
Adair*	G-30	3.2	11	2	3	SRS	N/A	12
Adair*	N-54	5	11	2	3	SRS	N/A	12
Adair*	N-72	5.6	11	2	3	SRS	N/A	12
Allamakee*	X-52	<1	11	6	7	SRS	N/A	12
Appanoose*	T-61	5	11	2	2.5	SRS and CLRS	18	12
Buchanan	D-22	5.8	12	4	8	SRS and CLRS	6	8
Buchanan	W-35	6.9	11	0	6	CLRS	6	
Buchanan	W-13	1.6	11	0	8	SRS and CLRS	6	6
Cedar*	F-28	<1	12	4	2	SRS	N/A	12
Cerro Gordo	B-20	<1	12	1	8	ELRS	N/A	12
Clinton	Z-2E	5.8	11	2.5	3	ELRS	N/A	4
Clinton	Y-32	2.3	11	3	4	ELRS	N/A	4
Crawford*	E-16	7	11	3	3	SRS	N/A	12
Jones**	E-34	3.7	11	2	6	ELRS	N/A	4
Lee*	J-50	4.8	12	2	6	SRS	N/A	12
Lee*	360th Ave	<1	12	2	6	SRS	N/A	12
Lee*	180th St	1	12	2	6	SRS	N/A	12
Linn**	E-16	4.7	12	4	6	ELRS	N/A	-
Madison	P-53	3	11	0	6	ELRS	N/A	7
Marion	G-40	7.2	11	3	7	ELRS	N/A	6
Marshall**	E-67	<1	11	2	4	ELRS	N/A	12
Marshall**	E-35	1.5	12	3	5	SRS	N/A	12
Montgomery	H-46	1.6	11	1	4	SRS and CLRS	16	6
Polk	F-70	1.7	12	2	3	ELRS	N/A	4
Webster	P-59	<1	12	–	–	SRS and CLRS	16	12
Winneshiek	A-52	1.1	11	4	8	SRS	N/A	12
Woodbury	D-22	12.5	11	4	10	ELRS	N/A	

* Constructed based on Iowa DOT Standard Road Plan PV-12 (https://iowadot.gov/design/SRP/IndividualStandards/epv012.pdf) or PV-13 (https://iowadot.gov/design/SRP/IndividualStandards/epv013.pdf)
** Rumble strip installation only on curved segments

Based on the responses collected from the country engineer survey, all secondary roadways with any combination of rumble strip installations were geocoded into a geographic information system (GIS) to determine their proximity to one another. Rumble strip installations were confirmed on the identified roadways by using a combination of the Iowa DOT GIMS and satellite imagery provided by Google Maps. Figure 22 displays the locations of the known rumble strip installations from the county engineer survey.

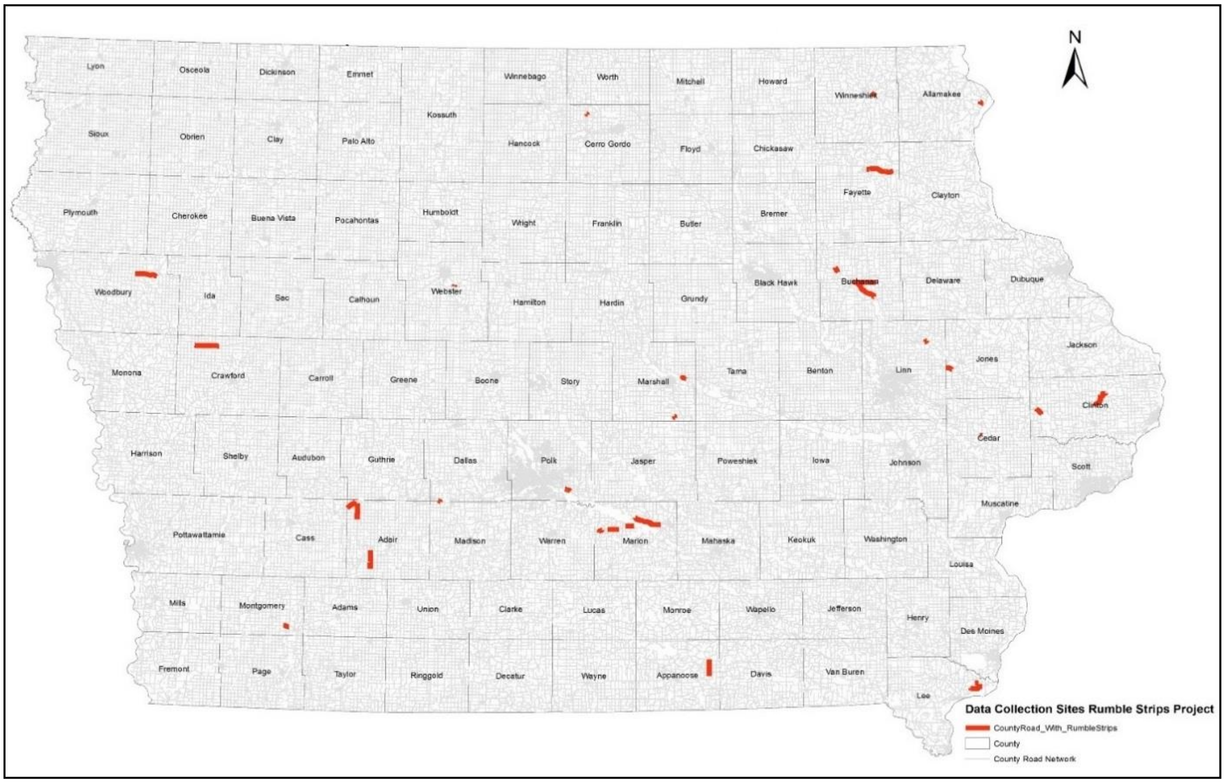


Figure 22. Rumble strip installations on secondary roadway system

To obtain diverse coverage of roadway segments with varying characteristics (i.e., rumble strip installation combinations, lane widths, shoulder widths, etc.), 53 sites were selected for data collection. Control locations were selected based on their proximity to locations with known rumble strip installations. Control locations were segments of roadway that did not have any rumble strips present. The focus of the project was mainly on the secondary roadway system; however, 16 sites along the primary roadway system were included as well. Primary roadways with lower traffic volumes and 12 ft lane widths were selected in order to fill in the gaps of the lane width/shoulder width combinations that were missing on the secondary roadway system. Table 14 shows the frequency of data collection at locations with specific characteristics related to curvature, geometry/alignment, lane width, average paved shoulder width, and average non-paved shoulder width.

Table 14. Frequency of locations with specific roadway characteristics

Segment	Treatment		Lane Width (ft)			Average Paved Shoulder Width (ft)							Non-paved Shoulder Width (ft)					
Type	Type	Count	10	11	12	0	1	2	3	4	5	6	< 2	2 to 4	4 to 6	6 to 8	8 to 10	> 10
Tangent	Control	9	2	5	2	1	5	1	2	0	0	0	1	3	2	3	0	0
Curve	Control	4	2	2	0	0	3	0	1	0	0	0	1	0	1	2	0	0
Tangent	CLRS and SRS	4	0	1	3	0	0	0	1	2	0	1	1	1	1	0	1	0
Curve	CLRS and SRS	4	0	3	1	0	0	1	0	0	3	0	0	1	1	0	0	2
Tangent	CLRS Only	2	2	0	0	0	2	0	0	0	0	0	0	0	2	0	0	0
Curve	CLRS Only	2	2	0	0	0	2	0	0	0	0	0	0	0	2	0	0	0
Tangent	EL Both Sides	5	1	1	3	0	2	1	2	0	0	0	0	0	2	0	3	0
Curve	EL Both Sides	6	1	2	3	0	0	1	3	1	1	0	0	0	3	2	1	0
Tangent	CLRS and 1 EL	1	0	1	0	0	0	0	0	0	1	0	0	0	0	0	1	0
Curve	1 EL	1	0	1	0	0	0	0	1	0	0	0	1	0	0	0	0	0
Tangent	SRS Only	8	0	5	3	0	0	3	1	4	0	0	1	5	1	1	0	0
Curve	SRS Only	7	1	6	0	0	0	1	1	2	2	1	3	3	0	1	0	0

4.2 Data Collection

Data were collected by a team of individuals between May 23, 2016 and July 15, 2016 on rural two-lane highways on the primary and secondary roadway systems in Iowa. The data collection team ranged from two to six members, who were trained at the start of the data collection period to ensure accuracy and consistency between individuals. A data collection specialist accompanied the trained individuals to the first two data collection locations to ensure that equipment and software was utilized correctly.

The vehicular interaction data were captured by a data collection trailer. The data collection trailer consisted of a 360° camera as well as a mountable Wavetronix radar sensor. A rotatable solar panel was also oriented appropriately to power the data collection trailer during the designated observation period. Figure 23 shows the data collection trailer on the inside of a horizontal curve after initial set up with the required components installed.

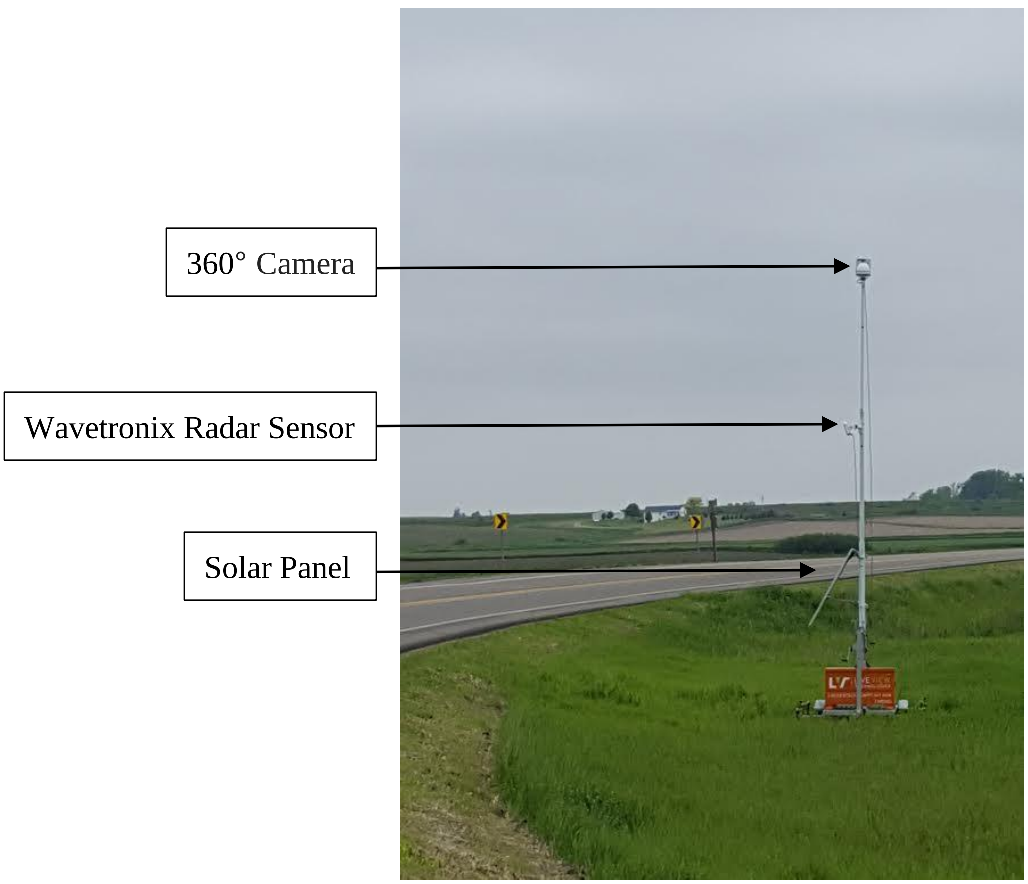


Figure 23. Data collection trailer components

The data collection trailer was placed in the nearest feasible roadside right of way at each data collection location. The trailer was placed on either side of the road at tangent locations and either inside or outside of the horizontal curve at curved locations. The reason for this placement was to maintain flexibility in the field when working with roadside ditches, which were often steep or unstable. The trailer was moved as necessary to ensure that there were no gaps in the rumble strips in the area of focus for the mounted data collection equipment (i.e., that the trailer was not placed alongside the gapped out portions of intermittent rumble strips). The data collection trailer was rotated as appropriate at each location to ensure that adequate sunlight would strike the solar panel to allow the data collection trailer to be powered for the minimum eight hours of daylight. The telescoping mast arm was raised to its maximum height at each location to ensure that all vehicles would be captured during the data collection period, including vehicles passing one another in opposing lanes of travel. The purpose of the camera was to provide a video record of all vehicular travel at each location during the data collection period. The Wavetronix sensor was utilized to capture the following characteristics of passing vehicles:

- Travel lane
- Vehicle length
- Vehicle speed
- Vehicle class
- Distance from Wavetronix sensor to vehicle
- Time of day

The purpose of installing both the camera and the Wavetronix sensor at each location was to compare the sensor output data to the video record captured by the camera to aid in the QA/QC process after data collection.

Following the installation of the data collection trailer, numerous roadway geometric characteristics were manually collected by the data collection team. All dimensions were measured using a folding engineer’s ruler and a flexible engineer’s tape measure. Rumble strip dimensions, including length, width, and spacing, were also collected at applicable locations. Roadway characteristics such as shoulder width, total pavement width, and other dimensions were collected, as illustrated in Figure 24. Unfortunately, appropriate means were not available to measure the rumble strips’ depths at an accuracy of less than half an inch. However, according to the data collection crews’ observations, most installations followed the suggestions of Iowa DOT Standard Road Plan PV-12 or PV-13 for the depth of the rumble strips, which is between 3/8 in. to 1/2 in.

Figure 24. Data collection roadway measurements

The distance between the roadway and the data collection trailer in the roadside right of way was also measured to maintain consistency across all data collection locations. This information was collected at each data collection location using a standardized form, as shown in Figure 25.

PERSONNEL AND EQUIPMENT			
Personnnel		Site Number	
Trailor			
Equipment			

SETUP DETAILS	
Cooridinates	
Roadway	
Nearest Town/City	
Start Time/Date	
Weather	
End Time/Date	
Weather	

MEASUREMENTS

Near Side		
Type	Value	Unit
RS Width		Inches
RS Length		Inches
RS Spacing		Inches
Gravel Shoulder Width		Feet
RS to Edge of Pavement		Feet
RS to Edge Line		Feet
Edge Line to Edge of Pavement		Feet
Cardinal Direction		
Roadway Direction		

Far Side		
Type	Value	Unit
RS Width		Inches
RS Length		Inches
RS Spacing		Inches
Gravel Shoulder Width		Feet
RS to Edge of Pavement		Feet
RS to Edge Line		Feet
Edge Line to Edge of Pavement		Feet
Cardinal Direction		
Roadway Direction		

Centerline		
Type	Value	Unit
RS Width		Inches
RS Length		Inches
RS to RS Spacing		Inches
Pair to Pair Spacing		Inches

Trailer		
Type	Value	Unit
To Edge of Pavement		Feet
To Edgeline		Feet
To Rumble Strip		Feet
To Centerline		Feet

Roadway		
Type	Value	Unit
Edgeline to Edgeline		Feet
Edge of Pavement to Edge of Pavement		Feet
Rumble Strip to Rumble Strip		Feet
Facility Type		
Passing Allowed		
Near Side Posted Speed Limit		MPH
Far Side Posted Speed Limit		MPH
Segment Type		

SITE SKETCH

Figure 25. Data collection roadway geometry form

Following the collection of roadway geometry information and rumble strip characteristics, the camera and Wavetronix installations on the data collection trailer were checked for accuracy before the data collection team left the location. As a part of this process, several preliminary passes were conducted using the data collection vehicles to help calibrate the sensor data. This calibration process included measuring the distances to the near and far edgeline and to the centerline as well as verifying that the sensor was installed perpendicular to roadway. In addition, the data collection team conducted several intentional encroachments over the centerline and edgeline to allow for verification of the subsequent data reduction process. Wireless communication was utilized to determine if the camera was facing the roadway and capturing an adequate frame of view for future QA/QC. The Wavetronix software was also consulted remotely to determine if the radar device was facing the roadway at an appropriate angle to collect reliable data. The software has a built-in accuracy meter, which was utilized to adjust the sensor appropriately before the team left the data collection location. Screenshots of the lane configuration program and the sensor software interface and an illustration of the physical sensor are shown in Figure 26. After the team left the data collection location, the installed devices were routinely monitored remotely to ensure accuracy during the data collection period.

Source: Smart Sensor HD user guide, Wavetronix.

Figure 26. Screenshots of the lane configuration program (left) and sensor interface (middle) and an illustration of a sensor device (right)

4.3 Quality Assurance/Quality Control

As mentioned previously, both a camera and a Wavetronix radar sensor were installed on the data collection trailer at each site to ensure the accuracy of the collected radar data. The purpose of the QA/QC was to identify and exclude any radar sensor errors or inconsistencies observed during the field data collection period. The three sources of information utilized during the QA/QC process were Wavetronix outputs in the form of Microsoft Excel spreadsheets, collected videos from the data collection trailer camera in the form of MP4 files, and the roadway characteristics information manually collected by the data collection team.

QA/QC was performed by comparing what was visually recorded by the camera to what was electronically recorded by the radar sensor. In order to compare the results collected by the Wavetronix radar sensor to the recordings taken by the video camera, numerous logic functions were generated in Excel to compare the Wavetronix output data to the collected roadway geometric characteristics. Using the developed logic functions, it was possible to insert the collected roadway geometry information for each site into the spreadsheet and determine if the vehicle crossed highly visible roadway attributes, such as the centerline, edgeline (near or far), or rumble strips (if present). The results of the logic functions were then compared to video captured concurrently on site, allowing for visual verification of the sensor output. Figure 27 shows an example of the logic function output and a screenshot of the corresponding video for a scenario where a school bus encroached the near edgeline.

Cross Edge of Pavement NearSide	Cross Near Edgeline	Hit Near Rumble Strip	Cross Center-line	Cross Edge of Pavement FarSide	Cross Far Edge Line FarSide	Hit Far Rumble Strip
0	1	0	0	0	0	0

Length (feet)	Width of Vehicles (feet)	Speed (MPH)
32	6	32.7

Figure 27. Example of the logic functions result compared to the video captured

Approximately 5% of all data collection records were manually checked in this manner at each data collection location, and any discrepancies between the logic functions and the collected video were flagged for further review.

During the manual QA/QC for the collected Wavetronix data, output errors and imprecisions were discovered. One major concern resulting from the QA/QC process was that adverse weather caused the sensor to periodically record false vehicular observations (i.e., to identify vehicles that that did not exist). Because the radar captures movement across the roadway within its range of observation, a heavy or steady rainfall sometimes caused the sensor to make observations that were not appropriate (i.e., no motorist was present at the time). Strong gusts of wind caused similar results, evident in the erroneous data from the Wavetronix output file corresponding to any of the adverse weather effects mentioned. An additional concern about data integrity was discovered regarding the presence of animals along the roadside. Observations that inappropriately identified animals as passing motorists were identifiable in the data output, based on the missing or extremely low speed that was recorded with the observation. Lastly, random errors occurred during extended periods of data collection. The source of these errors was not able to be determined; however, the errors were uncommon and represented a small percentage of the total errors that were discovered. These errors also involved missing or improbable speed data. In order to remove errors from the radar sensor output data, any observation that was missing speed information or had a speed less than 10 mph was not included in the data analysis. If the removal of data resulted in a significant loss of total site observations, the entire site was not included in any further data analysis procedures due to lack of accurate exposure. After the manual QA/QC procedure and the error elimination, as described above, a total of 45 sites were retained for data analysis.

Despite the robust QA/QC process, there are some minor limitations as to the accuracy of the data output from the sensors. In some cases, after observations were flagged for additional review, it was difficult to verify whether the radar sensor correctly identified a vehicle crossing a major roadway attribute (e.g., centerline or edgeline). Because only one camera angle was available at each data collection location, the perception of the video reviewer was the only means of determining the true lateral position of the motorist. Figure 28 contains two video review instances where it was difficult to determine if a particular roadway attribute was crossed during the video recording.

Figure 28. Examples of video review discrepancies

In the top set of images, the radar sensor determined that the pickup truck crossed the centerline; however, it is difficult to confirm from the available video imagery. In the bottom set of images, the radar sensor calculated that the tractor trailer crossed the far edgeline. Again, this is difficult to determine based on the available camera angle.

After data exploration and modeling began, a potential bias in the data was observed at locations where the trailer was located very near to the road due to right-of-way restrictions. In these cases, vehicles in the near lane were observed shifting away from the data collection trailer toward the centerline of the road, as shown in Figure 29.

Figure 29. Impact of data collection setup on vehicular lateral positions in near lane

A site-by-site assessment of the data showed that this effect was prevalent at those sites where the trailer was closer than 25 ft from the edge of the near travel lane. To mitigate this concern, sites where the trailer was located less than 25 ft from the edge of the near travel lane were excluded from subsequent analysis. Due to this limitation, all four sites where only centerline rumble strips were installed were excluded from the final dataset.

The data set that was used to analyze the operational impacts of rumble strips ultimately contained 46,087 observations from 24 sites across the state of Iowa. Table 15 contains the number and percentage of observations at sites having various characteristics of interest; the observations are separated by the lane in which they were observed.

Table 15. Observations by lane

Characteristic	Near Lane Count	Near Lane Percent	Far Lane Count	Far Lane Percent
Curve-Right	5,841	30.40%	952	3.54%
Curve-Left	706	3.67%	8,004	29.78%
Centerline and Shoulder Rumble Strips	7,894	41.09%	10,080	37.51%
Edgeline Rumble Strips Only	2,471	12.86%	2,202	8.19%
Shoulder Rumble Strips Only	4,244	22.09%	9,382	34.91%
Near Lane Passing	1,899	9.88%	1,902	7.08%
Far Lane Passing	6,209	32.32%	8,342	31.04%
Two-Way Passing	5,992	31.19%	10,245	38.12%
45 mph Speed Limit	2,503	13.03%	3,301	12.28%
50 mph Speed Limit	1,869	9.73%	1821	6.78%
55 mph Speed Limit	14,840	77.24%	21,753	80.94%
Motorcycle	369	1.92%	383	1.43%
Passenger Cars	16,867	87.79%	24,071	89.57%
Passenger Car w/Trailer, Bus	1,207	6.28%	1,412	5.25%
Single Unit Truck	147	0.77%	221	0.82%
Tractor-Trailer	618	3.22%	779	2.90%
Unknown Vehicle Type	4	0.02%	9	0.03%
10 Foot Lane Width	924	4.81%	1,128	4.20%
11 Foot Lane Width	9,918	51.62%	13,125	48.84%
12 Foot Lane Width	8,370	43.57%	12,622	46.97%
Shoulder Presence	16,709	86.97%	24,009	89.34%
Edgeline Encroachment	118	0.61%	654	2.43%
Centerline Encroachment	482	2.51%	40	0.15%
Observations	19,212	100.00%	26,875	100.00%

4.4 Statistical Methodology

Following the data collection and QA/QC processes, a series of logistic regression, or logit, models were estimated to examine the operational impacts of rumble strip installations on driver behavior, in particular, the frequency of encroachments upon lane markings. Logistic regression presents an appropriate modeling framework because the dependent variable (encroachment over the centerline or edgeline) is dichotomous. Under this framework, a logistic regression model is derived as follows:

$$ln\left(\frac{p_n}{1-p_n}\right) = \beta X_n + \varepsilon_n, \quad (2)$$

where:

- p_n is the probability of vehicle n encroaching on the centerline or edgeline
- β is a vector of estimable parameters

- X_n is a vector of observable characteristics (occupant, vehicle, roadway, environmental, etc.)
- ε_n is an independent and identically distributed error term

The logistic regression model assumes that the error terms (ε_n) are independently and identically distributed (IID), which is potentially problematic because various site-specific factors, such as roadway geometry or the presence of rumble strips, would be correlated for vehicles observed on the same road segment. This correlation results in a violation of the IID assumption, which could result in biased or inefficient parameter estimates. The random effects model is a generalization of the standard logistic regression model that relaxes the IID assumption by allowing the constant term of the regression to vary across road segments. Further details of the statistical methods can be found elsewhere (Washington et al. 2011).

4.5 Analysis Results

Due to limitations of the data (e.g., difficulty in clearly identifying far side edge and centerline encroachment), separate logit models were estimated to examine the impacts of rumble strips on road user behavior under the following scenarios: near lane cross edgeline and far lane cross centerline. Furthermore, two iterations for each model are presented, one that only includes the types of rumble strips installed as predictor variables and another fully specified model in which other explanatory characteristics are considered. The results of using the simple, naïve pooled models to examine the impacts of rumble strips on edgeline and centerline encroachments are provided in Table 16 and Table 17.

Table 16. Simple logit model for edgeline encroachments

Parameter	Estimate	Std Error	z value	Pr(>|z|)
Intercept	-4.532	0.144	-31.554	2.00E-16
Centerline and Shoulder Rumble Strips	-0.911	0.224	-4.068	4.73E-05
Shoulder Rumble Strips Only	-0.725	0.258	-2.816	0.00487
Edgeline Rumble Strips Only	-0.710	0.313	-2.269	0.02326

Table 17. Simple logit model for centerline encroachments

Parameter	Estimate	Std Error	z value	Pr(>|z|)
Intercept	-6.5912	0.2238	-29.457	2.00E-16
Centerline and Shoulder Rumble Strips	-1.5282	0.6191	-2.468	1.36E-02
Edgeline Rumble Strips Only	1.735	0.3307	5.247	1.55E-07

It is highly likely that the act of a vehicle encroaching on the roadway edge or centerline is the result of a wide array of factors, and not simply due to the presence of rumble strips. In order to better understand the relationship between edge and centerline encroachment and the roadway environment, an additional series of logit models was estimated. These models considered the effects of rumble strips as well as the effects of various roadway operational, vehicular, and geometric characteristics. The results of these fully specified random effects logit models are presented for edgeline encroachments and centerline encroachments in Table 18 and Table 19, respectively.

Table 18. Fully specified logit model for edgeline encroachments

Fixed Effects	Estimate	Std Error	z value	Pr(>|z|)
Intercept	15.3353	4.425	3.466	5.29E-04
Centerline and Shoulder Rumble Strips	-0.824	0.5954	-1.384	1.66E-01
Shoulder Rumble Strips Only	-1.0551	0.6503	-1.623	1.05E-01
Edgeline Rumble Strips Only	-1.1839	0.6778	-1.747	0.08067
Near Lane Shoulder Presence	2.066	1.4677	1.408	0.15922
Natural Log of Lane Width	-9.4162	1.8188	-5.177	2.3E-07
Curve-Right	1.1589	0.4581	2.53	1.14E-02
Speed Limit less than 55 MPH	-1.0621	0.7854	-1.352	0.1763
Opposing Lane Passing	0.6354	0.4796	1.325	0.18521
Passenger Car w/Trailer, Bus	1.1662	0.2698	4.323	1.54E-05
Single Unit Truck	1.3172	0.5921	2.224	2.61E-02
Tractor-trailer	1.4992	0.3114	4.815	1.48E-06

Table 19. Fully specified logit model for centerline encroachments

Fixed Effects	Estimate	Std Error	z value	Pr(>|z|)
Intercept	-64.339	14.4903	-4.44	8.99E-06
Centerline and Shoulder Rumble Strips	-2.5591	2.3216	-1.102	0.27032
Edgeline Rumble Strips only	3.0727	2.2184	1.385	0.16602
Natural Log of Lane Width	22.1168	5.9515	3.716	0.0002
Curve-Right	3.6152	2.6271	1.376	0.1688
Speed Limit Less than 55 MPH	4.1229	2.5257	1.632	0.1026
Tractor-Trailer	2.8096	0.4545	6.182	6.32E-10

The random effects logit framework was used to account for unobserved site-specific characteristics that may influence the likelihood of encroachment.

The result of using the random effects framework is that the intercept of each of the models is allowed to vary randomly from site to site. For the edgeline encroachment model, the variance associated with the random effect was estimated to be 0.505, while the variance of the random effect in the centerline encroachment model was estimated to be 8.864.

4.6 Discussion

The simple logit models presented in Table 16 and Table 17 provide high-level insight regarding the operational effects of various rumble strip installation types. The edgeline encroachment results illustrate that all three rumble strip installation types are associated with a decreased likelihood of edgeline encroachment, with the combination of centerline and shoulder rumble strips being associated with the lowest probability of encroachment. Intuitively, one might expect that edgeline rumble strips would have the largest impact on edgeline encroachment, followed by shoulder and then shoulder and centerline rumble strips. This pattern seems likely primarily for two reasons. First, rumble strips installed directly on the edgeline may cause drivers to position their vehicles closer to the centerline than would be the case if shoulder rumble strips were present. Second, the presence of a centerline rumble strip seems likely to cause drivers to travel closer to the edgeline. One potential explanation for why this was not the observed trend is that the presence of rumble strips on both the shoulder and centerline results in increased driver awareness and therefore fewer edgeline encroachments.

The centerline encroachment results show that the combination of centerline and shoulder rumble strips decreased the frequency of centerline encroachments, which is consistent with general research that has shown drivers to shift away from the centerline when a CLRS is installed. In contrast, the presence of edgeline rumble strips tended to shift vehicles away from the edgeline and toward the centerline of the road. Interestingly, this same effect was not found for shoulder rumble strips. This may be due, at least in part, to the fact that the shoulder rumble strips are placed outside of the edgeline. There were very few instances of drivers veering this far past the edgeline in the field studies, so there is likely to be significantly less incidental contact in the presence of shoulder rumble strips.

The subsequent discussion focuses on the fully specified models, which provide insight into the effect of rumble strips while controlling for other factors that influence variability in lateral position among the observed data. The performance of rumble strips relative to roadway geometric and operational characteristics is of particular interest for the planning of future rumble strip installations. Each of the following subsections discusses the observed effects of pertinent roadway geometric and operational characteristics on the likelihood of an edgeline or centerline encroachment. When taken in conjunction with the observed effects of the rumble strips, these models provide insight into when it may be appropriate to install rumble strips in order to reduce instances of vehicular encroachment on roadway edgelines and centerlines.

4.6.1 Rumble Strip Installation Type

As noted in the preceding discussion, all rumble strip installation types were found to be associated with a reduced likelihood of encroachment. While this effect is consistent with expectations for centerline and edgeline rumble strips, it is interesting to note that the combination of centerline and shoulder rumble strips resulted in the lowest probability of edgeline encroachment. This may be reflective of drivers being more aware of their surrounding environment, as suggested by prior research (Gates et al. 2012), or it may be an artifact of the larger right of way available at such locations.

For centerline encroachments, vehicles were significantly less likely to pass into the opposing lane if centerline rumble strips were installed. Similarly, if only edgeline rumble strips were installed, these tended to cause drivers to shift away from the shoulder and toward the centerline of the roadway, increasing the number of centerline encroachments. Taken collectively, the results of these analyses clearly indicate that rumble strips can effectively reduce the likelihood of edgeline and centerline encroachment, thus reducing the potential for a lane departure crash.

4.6.2 Presence of a Paved Shoulder

The presence of a paved shoulder was associated with an increased likelihood of an edgeline encroachment. The reasoning behind this observation is fairly intuitive: the presence of a shoulder likely causes drivers not to worry about their vehicle departing the roadway, and thus drivers cross the edgeline more frequently than otherwise. Given that shoulders are shown to be, at a minimum, associated with an increased likelihood of edgeline encroachment and possibly also an increased likelihood of centerline encroachment, locations where paved shoulders are present would likely benefit from the installation of shoulder and centerline rumble strips.

4.6.3 Lane Width

Prior to estimating the logit models, the general expectation was that as lane width decreases, the likelihood of observing an edgeline or centerline encroachment would increase. The results are consistent with this expectation, in that edgeline encroachments were found to increase in likelihood as lane width decreased.

Interestingly, the results of the centerline encroachment analysis show that roadways with narrower lanes tended to experience fewer centerline encroachments. While this may seem counterintuitive, the finding may suggest that drivers are potentially positioning their vehicles farther from the centerline in narrow lane situations. This would suggest that drivers are compensating for the risk of a potential collision with an oncoming vehicle by positioning themselves nearer to the edgeline, even though there is less space available. Consequently, this result provides support for installing centerline rumble strips even on pavements with narrow lanes, because the chance of incidental contact is likely to be low. In addition, in order to minimize incidental centerline encroachments, it is advisable that only shoulder rumble strips be installed (instead of edgeline rumble strips) on pavements with 10 ft lanes.

4.6.4 Horizontal Alignment

As vehicles travel through curved roadway segments, centrifugal forces act on the vehicle, pushing it away from the center of the curve. Superelevation present in curved roadway segments is designed specifically to counteract this force, therefore making it difficult to hypothesize how horizontal alignment would affect various lane delineation encroachments. In this study, three alignment scenarios were considered: tangent, right curve, and left curve (with curve directions relative to the direction of travel). In general, encroachments were most likely to occur on curves, particularly right-hand curves. This result suggests that some drivers overcompensate for curve radius, which results in edgeline encroachment, while other drivers undercompensate, which results in centerline encroachment. The installation of rumble strips is expected to decrease the frequency of such encroachments, providing further benefits in reducing crash risks. One limitation of this study is that vehicles were observed at various points along a curve depending on the site. Future research is warranted to better understand the dynamics as vehicles are entering, exiting, or travelling through a horizontal curve.

4.6.5 Posted Speed Limit

Roadways with lower posted speed limits were less likely to have vehicles encroaching on the edgeline. In contrast, centerline encroachments were more likely to occur at lower speeds. Collectively, these results suggest that on lower speed roadways, vehicles tend to travel closer to the centerline. This may reflect the fact that drivers are more comfortable traveling closer to oncoming traffic as roadway speed decreases.

4.6.6 Passing

Vehicles were more likely to encroach on the edgeline at locations where only oncoming traffic was allowed to pass. This result suggests that drivers tend to position their vehicles further from the centerline in these situations. In terms of centerline encroachment, no discernible effect could be found regarding passing. A likely reason for this observation is that despite study sites being located in passing zones, very few vehicles were actually observed performing a passing maneuver.

4.6.7 Vehicle Type

Wider vehicles require more room to operate; therefore, one would expect that wider vehicles would likely be associated with an increased likelihood of lane marking encroachments. This expectation was largely consistent with the results of the models. Specifically, large vehicles were significantly more likely to encroach on either the centerline or edgeline of the roadway.

5. RUMBLE STRIP SURVEY

A survey was conducted to gauge public feedback on the use of rumble strips on two-lane highways in Iowa. The rumble strip survey consisted of 19 questions that explored the public's thoughts on and previous interactions with both centerline and shoulder or edgeline rumble strips. The questions addressed respondents' previous experiences while driving on roads with a CLRS and/or SRS; feedback on potential problems rumble strips may cause for nearby residents, bicyclists, or pedestrians; and general opinions about the effectiveness of rumble strips on two-lane highways. A description of the purpose of rumble strips and an image of rumble strips were presented to respondents at the start of the survey to further describe the roadway countermeasures in question and thus ensure accuracy and negate any potential confusion among survey respondents.

5.1 Survey Implementation

The rumble strip survey was distributed to any interested member of the public at 10 driver's licensing offices around the state of Iowa. Participating cities included Ames, Ankeny, Carroll, Cedar Rapids, Council Bluffs, Dubuque, Fort Dodge, Iowa City, Mason City, and Waterloo. Figure 30 shows the spatial distribution of the surveyed cities, while Figure 31 shows the spatial distribution of the survey participants.

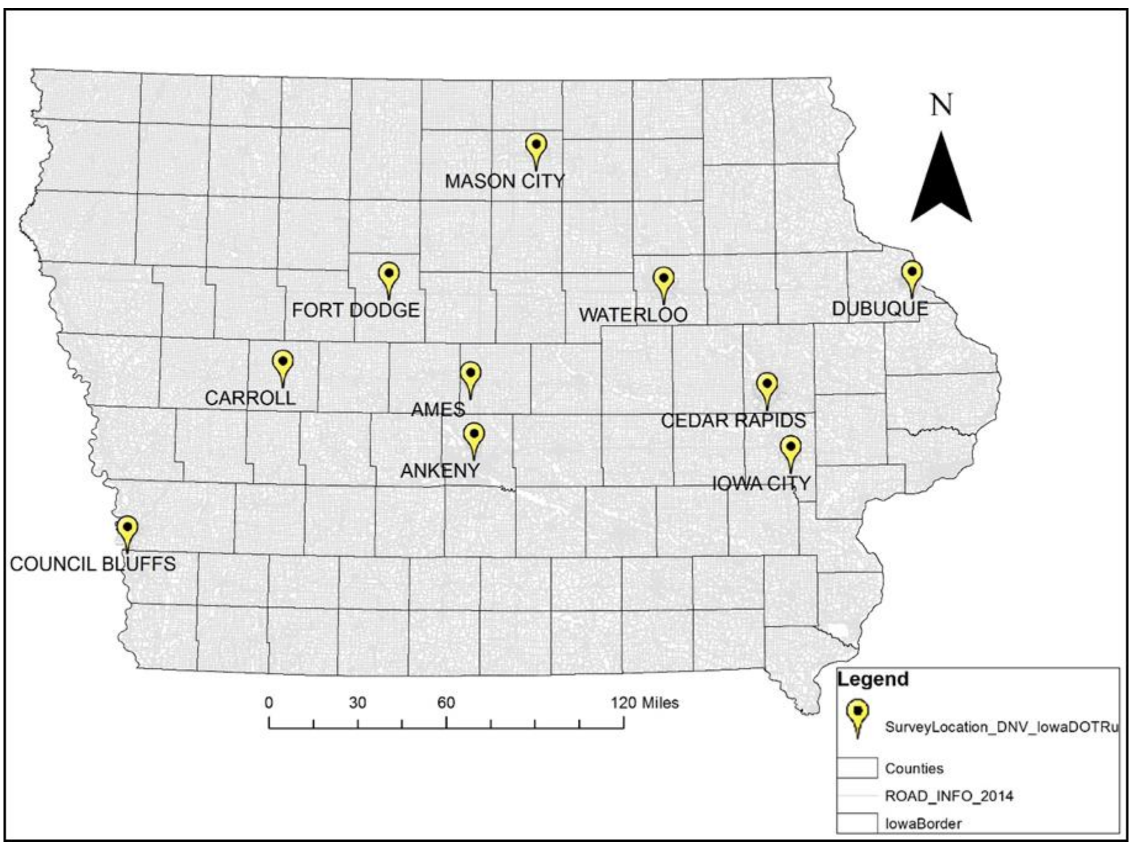


Figure 30. Spatial distribution of survey locations

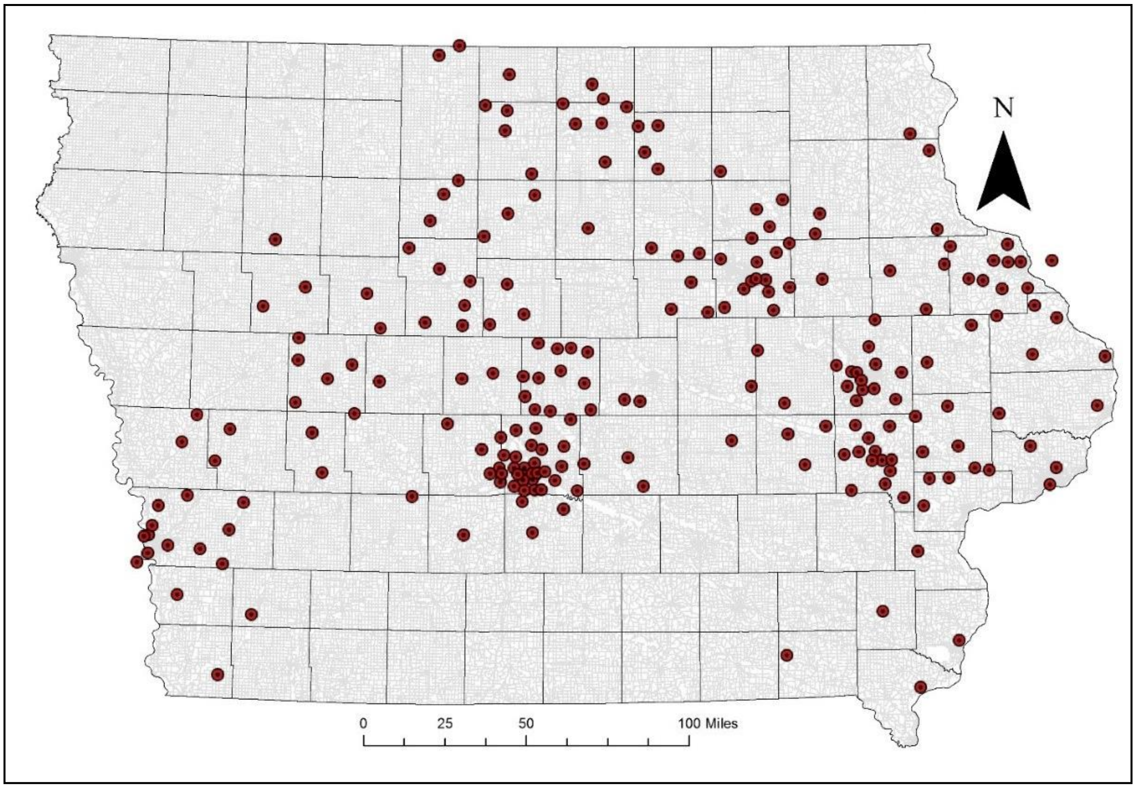


Figure 31. Spatial distribution of survey participants

The surveys were distributed to individuals from approximately 8:30 a.m. to 5:00 p.m. at each location. Each location was surveyed for one day. The surveys were voluntary and completely anonymous. A total of 1,477 surveys were returned to the survey administrators. The frequency and percentage of returned surveys by city is shown in Table 20.

Table 20. Survey completion by city

City	Frequency	Percent	Cumulative Frequency	Cumulative Percent
Ames	104	7.04	104	7.04
Ankeny	286	19.36	390	26.40
Carroll	22	1.49	412	27.89
Cedar Rapids	245	16.59	657	44.48
Council Bluffs	138	9.34	795	53.83
Dubuque	151	10.22	946	64.05
Fort Dodge	53	3.59	999	67.64
Iowa City	175	11.85	1174	79.49
Mason City	102	6.91	1276	86.39
Waterloo	201	13.61	1477	100.00

The survey that was presented to motorists at each location is shown in Appendix B. The purpose of the survey was to gauge public familiarity with rumble strips and to determine whether the advantages/disadvantages of rumble strips were clear to the general public. The survey concluded by soliciting the basic demographic information of the participant. Frequency tables for all survey question responses are displayed in Appendix C. The frequency, percent, cumulative frequency, and cumulative percent for each answer option are displayed for each survey question. The number of missing or incomplete responses is also tabulated for each survey question.

5.2 Survey Results

Approximately the same number of males and females completed the survey. About half of the survey participants were under the age of 34 (47%). Given the extensive application of rumble strips on two-lane highways within Iowa, the number of survey participants who were familiar with rumble strips (95%) and have driven where they were installed (71% and 88% for centerline and shoulder rumble strips, respectively) was expected to be high. Additionally, 89% of surveyed motorists would like to see the installation of rumble strips on two-lane highways continue throughout the state. This finding indicates that rumble strip installations are relatively well received by the driving public and are a favorable form of lane keeping technology.

The collected survey results demonstrate that a majority of motorists have had positive experiences with rumble strips while driving along two-lane rural highways. The results of the survey show that the safety benefits of rumble strips appear to be well recognized by Iowa motorists. Interestingly, there was not a strong general perception of the potential adverse impacts of rumble strips. A large majority of respondents supported the future installation of rumble strips along two-lane highways. Survey results indicated that the rumble strips already installed on two-lane highways in Iowa have successfully kept motorists within the correct travel lane during times of inattentiveness without impacting vehicle speed or the flow of traffic.

A vast majority (92%) of the survey participants noted that the current rumble strip designs used in Iowa provide sufficient feedback to the driver in terms of both audible noise and vehicular vibration. Although most contact with rumble strips was unintentional during normal driving maneuvers, 27% of respondents recall contacting the rumble strips while temporarily distracted. An additional 19% of the surveyed individuals contacted the rumble strips when tired or fatigued, providing support for the assertion that rumble strips improve lane keeping when motorists are inattentive or drowsy. The currently installed rumble strips have also alerted motorists during adverse weather conditions and nighttime driving, with 26% and 15% of survey respondents, respectively, noting contact with rumble strips during these limiting conditions.

Similarly, the general effectiveness of rumble strips was also well understood by the survey participants. Rumble strips were described as “very effective” by most survey respondents for all five surveyed driving conditions: daytime, nighttime, clear weather, rain, and snow. Of the five conditions, respondents found rumble strips to provide the most effective feedback during nighttime conditions (64%). Rumble strips were the next most effective in rain (55%) and snow (46%) conditions. Rumble strip feedback was least important in daytime (44%) and clear weather (43%) conditions, although rumble strips were still rated as “very effective” in these conditions by most survey participants.

One unique benefit of rumble strips, as determined by the survey, is that the effect experienced by drivers is very intense when needed (e.g., when a vehicle leaves the roadway), but rumble strips do not impact the flow of traffic. The survey determined that motorists’ speeds (64%) were not impacted by the presence of rumble strips along a two-lane rural highway. Additionally, the presence of a CLRS was not significant enough to discourage the passing of a slower moving vehicle on two-lane highways. Approximately 68% of the survey participants noted that their frequency of passing was unaffected by the presence of a CLRS, which provides support for prior research that has confirmed a minimal impact on passing maneuvers through field studies (Gates et al. 2012).

Despite the well-documented safety benefits, rumble strips have been shown to generate audible noise for nearby residents and raise additional concerns for non-motorists using the roadway shoulder. While 89% of the survey participants did not live near a two-lane highway where rumble strips had been installed, approximately 10% of respondents felt that the noise generated by a vehicle contacting the rumble strips was an issue for such residents. Of the survey participants who did live near a two-lane highway where rumble strips had been installed (11% of all survey participants), 95% thought that rumble strips provide sufficient feedback, and approximately 85% support the continued installation of rumble strips on two-lane highways.

Given the fact that rumble strips in Iowa are most prevalent on rural roads, 88% of the survey participants did not bike on two-lane highways where rumble strips were installed. Out of those 12% of respondents who did bike on two-lane highways with rumble strips in place, half thought that the presence of rumble strips might create problems for bicyclists. Likewise, while 87% of the survey participants had not walked or jogged on such roadways, less than 20% of those who had walked or jogged on such roadways thought that the presence of rumble strips may create problems for walkers/joggers. It should be noted that most participants did not utilize two-lane rural highways as non-motorists, and most respondents were unsure whether rumble strips presented a problem for bicyclists or pedestrians. Approximately 15% of respondents felt that rumble strips posed issues for bicyclists, while 6% felt similarly about pedestrians. Furthermore, of those 11% of respondents who lived near a two-lane highway with rumble strips installed, the percentage of those who biked or jogged increased to 38% and 28%, respectively, given the fact that those respondents lived in the vicinity of two-lane highways. It should be noted that only 18% and 11% of those respondents who lived near a two-lane highway with rumble strips installed felt that rumble strips create problems for bicyclists and joggers, respectively.

Overall, the results of the survey indicated that motorists are very supportive of Iowa’s rumble strip initiative. Survey respondents felt that rumble strips improved safety under a diverse range of settings and, in general, there were limited concerns as to incidental impacts on noise and non-motorized users. Most survey respondents also noted that the impact of rumble strips is evident in times of need (when a vehicle departs the roadway unintentionally) but is minimal during normal operations (having no effect on speed or passing). Consequently, these results suggest that the public is generally supportive of rumble strips, though caution should be exercised in areas where noise is a concern or where large volumes of pedestrians or bicyclists are expected.

6. CONCLUSIONS AND RUMBLE STRIP INSTALLATION GUIDANCE

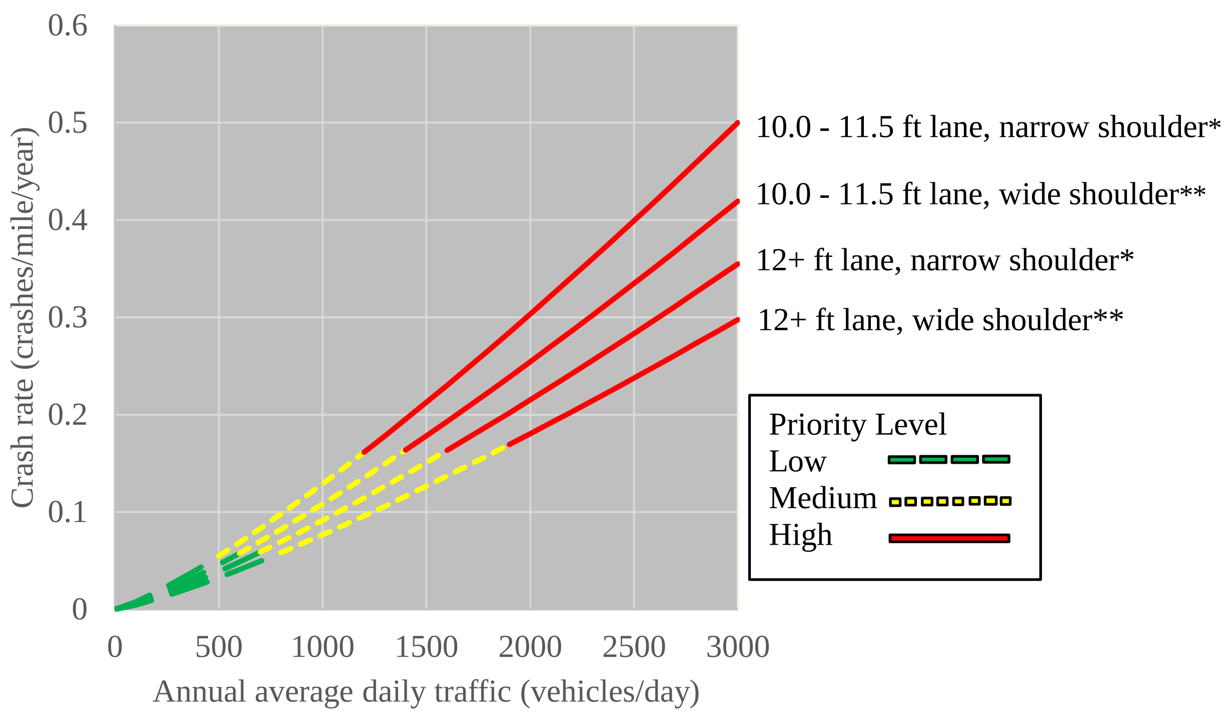
This study involved a comprehensive investigation of the effects of rumble strips on traffic operations and safety. This included a statewide analysis of the safety performance of two-lane highways where centerline rumble strips and/or shoulder/edgeline rumble strips have been installed. The results of this analysis show that both types of rumble strips tend to lead to significant reductions in the number of target (i.e., cross-centerline or cross-edgeline) crashes. The crash reduction is greatest for CLRS, although both SRS and ELRS were found to reduce crashes as well. Interestingly, a synergistic effect was identified, wherein the combination of a CLRS with SRS/ELRS led to further reductions in lane departure crashes.

Based on the results of these safety analyses, guidance is provided on the installation of rumble strips on Iowa’s secondary road network. First, details are provided regarding the effects of lane width, shoulder width, and traffic volume on the rates of cross-centerline and cross-edgeline crashes on the secondary system. These summaries can be used to prioritize candidate segments for rumble strip installation based on site-specific factors. Subsequently, an economic analysis is presented that considers these same site-specific factors in demonstrating the cost-effectiveness of rumble strips in reducing cross-centerline and cross-edgeline crashes. Collectively, these resources can be used to aid county road agencies in the proactive deployment of rumble strips on the secondary network.

6.1 Crash-based Guidance for Centerline Rumble Strip Installation

In order to provide the Iowa DOT and county road agencies with specific guidance regarding the installation of rumble strips on the secondary network, the secondary network was stratified into three priority levels (i.e., low, medium, and high) for both centerline rumble strip installation and edgeline/shoulder rumble strip installation. This procedure allowed for the identification of specific combinations of roadway geometric characteristics (i.e., lane width and shoulder width) and traffic volumes that could potentially benefit the most from rumble strip installation.

Figure 32 illustrates that road segments with traffic volumes from as low as 1,200 vehicles per day for segments with narrow lanes and shoulders to 1,900 vehicles per day for segments with wider lanes and shoulders are likely to experience the highest rate of centerline-related crashes per mile per year and therefore stand to benefit the most from centerline rumble strip installation.



*paved shoulders of less than 2 ft or non-paved shoulders of less than 4 ft
** paved shoulders of at least 2 ft or non-paved shoulders of at least 4 ft

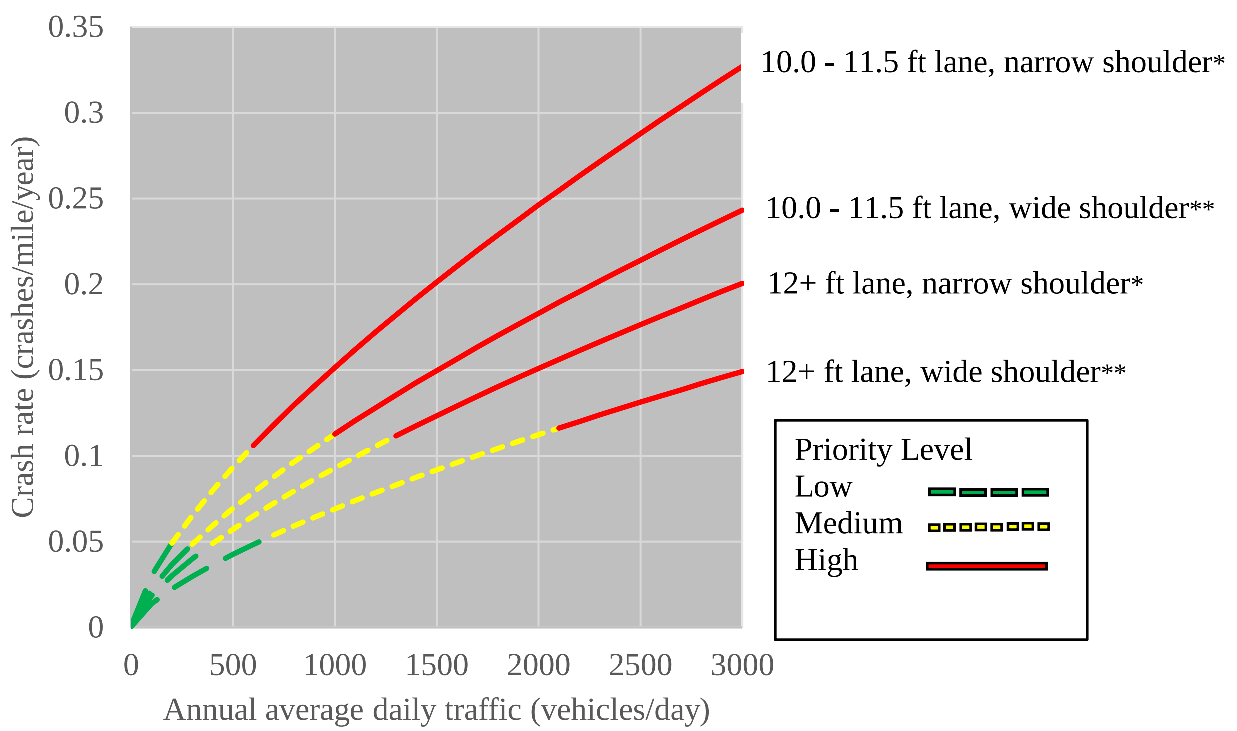
Figure 32. Centerline rumble strip installation priority

These locations are classified as high-priority candidates for centerline rumble strip installation. Road segments with minimum traffic volumes from 500 vehicles per day for segments with narrow lanes and shoulders to 800 vehicles per day, depending on geometric characteristics, for segments with wider lanes and shoulders generally experience an elevated rate of centerline-related crashes and are therefore considered medium-priority centerline rumble strip installation locations. Road segments below these volume ranges generally experience fewer centerline-related crashes per mile per year and are therefore considered low-priority centerline rumble strip installation locations.

6.2 Crash-based Guidance for Shoulder/Edgeline Rumble Strip Installation

The expected rate of edgeline-related crashes was found to vary widely depending on the specific geometric configuration of the roadway. Lanes narrower than 12 ft in width, particularly those with narrow shoulders (less than 2 ft paved or less than 4 ft non-paved) generally experience the highest rate of edgeline-related crashes.

Figure 33 illustrates that road segments with narrow lanes and shoulders experience the highest rates of edgeline-related crashes when traffic volumes are as low as 600 vehicles per day.



*paved shoulders of less than 2 ft or non-paved shoulders of less than 4 ft
** paved shoulders of at least 2 ft or non-paved shoulders of at least 4 ft

Figure 33. Edgeline/shoulder rumble strip installation priority

In contrast, segments with wider, 12 ft lanes and wider shoulders do not experience a similar edgeline-related crash rate until traffic volumes reach 2,100 vehicles per day. The medium-priority segments consist of roadways with traffic volumes from 200 to 700 vehicles per day, depending on the specific geometric configuration of the roadway. Roadways with traffic volumes below these levels experience a relatively low edgeline-related crash rate and are considered low-priority installation locations.

Figure 32 and Figure 33 and provide a detailed prioritization scheme that indicates when the installation of rumble strips is likely to be most beneficial. It is worth noting that the crash frequency analysis conducted in this study found no adverse effects on roadway safety due to the presence of rumble strips on road segments. Therefore, road segments with relatively low traffic volumes could still potentially benefit from rumble strip installation.

6.3 Benefit/Cost Analysis of Rumble Strips Installation

The preceding section outlined the expected rates of cross-centerline and cross-edgeline crashes under various combinations of lane widths, shoulder widths, and traffic volumes. To estimate the cost-effectiveness of rumble strip installation under these scenarios, a benefit/cost (B/C) analysis was conducted to compare the crash cost savings to the installation costs associated with centerline rumble strips, shoulder/edgeline rumble strips, and the combination of both. Table 21 provides unit costs for rumble strip installation on a per-mile basis from the Iowa DOT. The installation costs were obtained from Bid Express, which is a secure internet bidding service that allows access to detailed bid information from all agencies using this service between 2012 and 2017. Historical low, average, and high prices for rumble strip installations in a variety of formats, including by proposal, by item, and by contractor, are available through this service.

Table 21. Installation costs for centerline and shoulder rumble strips

Rumble Strip Types	Installation Cost (per mile)
Shoulder Rumble Strips (both sides)	$4,551.36
Centerline Rumble Strips	$2,095.63
Centerline and Shoulder Rumble Strips	$6,646.99

In order to estimate the benefits, or crash cost savings, associated with the reduction in crashes due to rumble strip installation, comprehensive crash cost data were obtained from the *Highway Safety Manual* (AASHTO 2010) and are summarized in Table 22 by KABCO severity level. These costs include wage and productivity losses, medical expenses, administrative expenses, motor vehicle damage, and employers' uninsured costs, as well as a measure of the value of lost quality of life.

Table 22. Crash costs by KABCO severity level

Injury Severity Level	Comprehensive Crash Cost
Fatality (K)	$4,008,900
Disabling Injury (A)	$216,000
Evident Injury (B)	$79,000
Possible Injury (C)	$44,900
PDO (O)	$7,400

The SPFs developed as a part of this study provide estimates of the expected reduction in target crashes (i.e., cross-centerline and cross-edgeline) associated with the installation of rumble strips. Because these estimates are provided with respect to total crashes, a weighted average cost was estimated for each type of target crash based on the proportion of crashes for each injury severity level occurring on the secondary road network. These calculations are summarized in Table 23, which shows cross-centerline target crashes to generally be more severe and, therefore, more costly.

Table 23. Determination of weighted-average crash cost

Crash Type	Injury Severity	Proportion	Crash Cost ($)	Weighted Average Cost
Cross-Edgeline	K	2.1%	$4,008,900	$126,597.73
	A	7.1%	$216,000	
	B	18.1%	$79,000	
	C	21.2%	$44,900	
	PDO	51.5%	$7,400	
	Total	100.0%		
Cross-Centerline	K	3.2%	$4,008,900	$174,238.60
	A	8.7%	$216,000	
	B	18.0%	$79,000	
	C	15.7%	$44,900	
	PDO	54.4%	$7,400	
	Total	100.0%		
Total Target Crashes	K	2.7%	$4,008,900	$153,111.60
	A	8.0%	$216,000	
	B	18.0%	$79,000	
	C	18.2%	$44,900	
	PDO	53.1%	$7,400	
	Total	100.0%		

In order to provide a basis for county road agencies to determine the cost-effectiveness of various rumble strip installations (centerline-only, edgeline-only, or centerline and edgeline), a series of charts was developed documenting the benefit/cost ratio of rumble strips on a per mile basis. The benefits were estimated by multiplying the weighted average crash costs calculated above by the estimated reduction in crashes based on the results of the safety analysis presented in Chapter 3.

Figure 34 through Figure 37 illustrate the benefit/cost ratios associated with rumble strip installations for the following lane and shoulder configurations assuming a service life of 7 years and a discount rate of 4%:

- 12 ft lanes and paved shoulders less than 2 ft or non-paved shoulders less than 4 ft
- Lanes less than 12 ft and paved shoulders less than 2 ft or non-paved shoulders less than 4 ft
- 12 ft lanes and paved shoulders of at least 2 ft or non-paved shoulders of at least 4 ft
- Lanes less than 12 ft and paved shoulders of at least 2 ft or non-paved shoulders of at least 4 ft

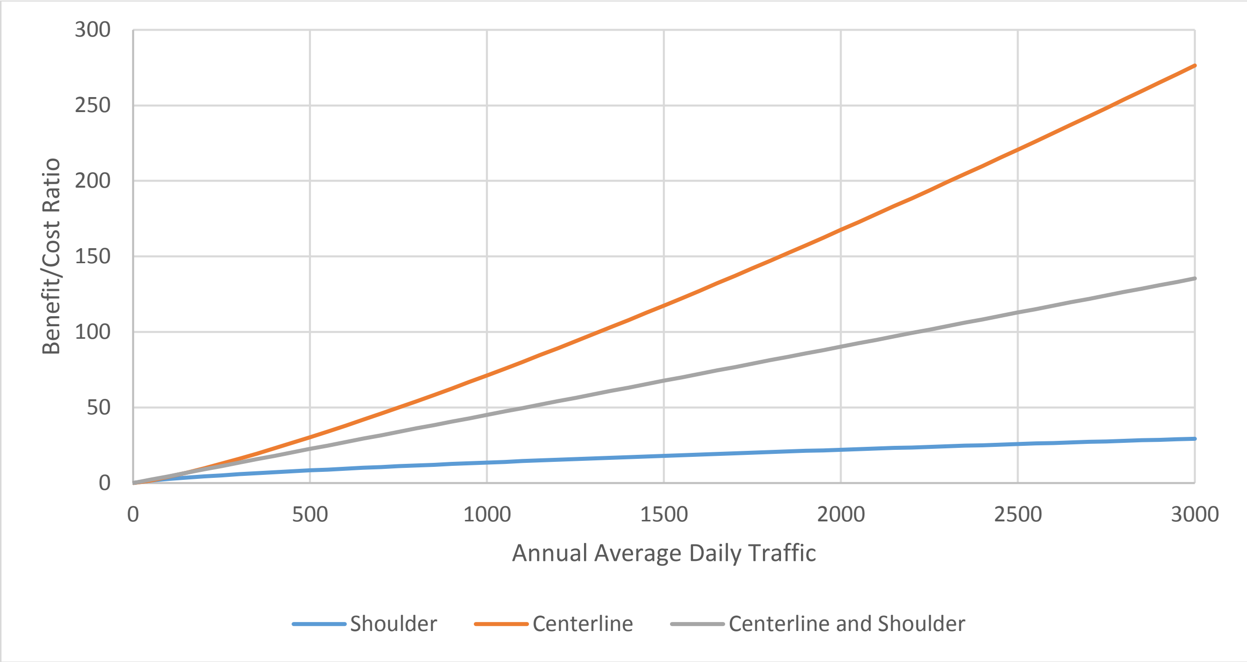


Figure 34. Benefit/cost ratios for rumble strip installations versus annual average daily traffic: lane width less than 12 ft, paved shoulder less than 2 ft or non-paved shoulder less than 4 ft

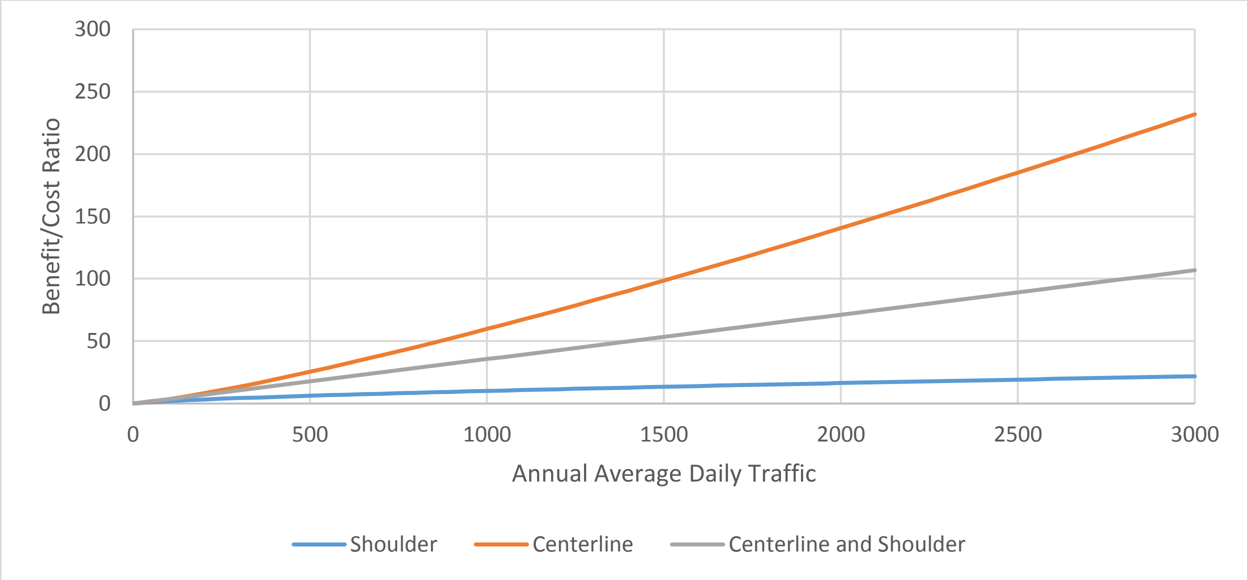


Figure 35. Benefit/cost ratios for rumble strip installations versus annual average daily traffic: lane width less than 12 ft, minimum 2 ft paved shoulder or 4 ft non-paved shoulder

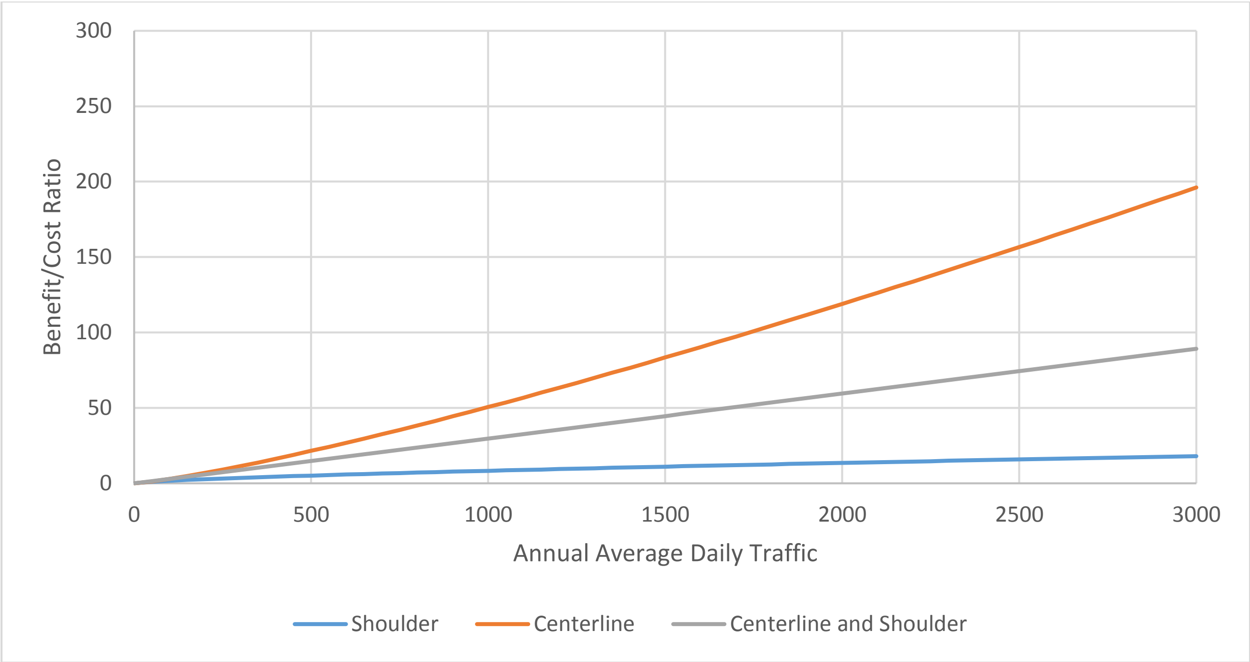


Figure 36. Benefit/cost ratios for rumble strip installations versus annual average daily traffic: 12 ft lanes, paved shoulder less than 2 ft or non-paved shoulder less than 4 ft

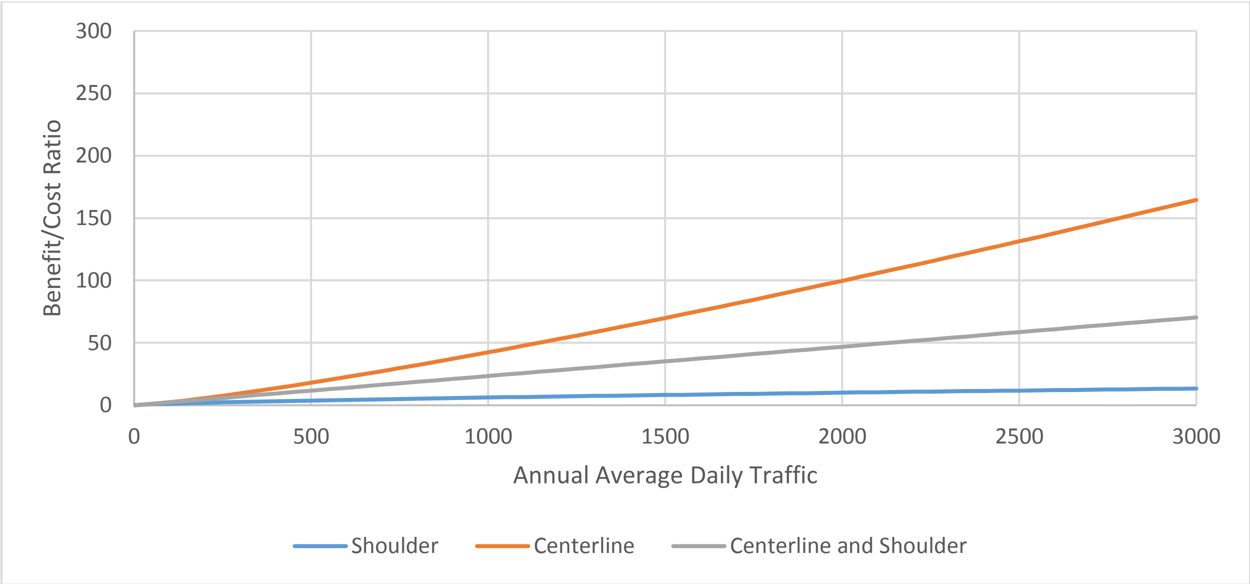


Figure 37. Benefit/cost ratios for rumble strip installations versus annual average daily traffic: 12 ft lanes, minimum 2 ft paved shoulder or 4 ft non-paved shoulder

These figures provide compelling evidence of the cost-effectiveness of rumble strips in reducing lane departure crashes. Centerline rumble strips become cost-effective when traffic volumes are between 50 and 80 vehicles per day, shoulder rumble strips become cost-effective when traffic volumes are between 30 and 80 vehicles per day, and the combination of centerline and shoulder rumble strips becomes cost-effective when traffic volumes are between 25 and 45 vehicles per day. For all geometric conditions considered, centerline rumble strips were the most cost-effective installation type, except at locations where traffic volumes were extremely low. The benefit/cost ratios estimated for these scenarios collectively suggest that rumble strips are a cost-effective crash countermeasure nearly everywhere on the two-lane rural highway network.

One additional item of interest that was investigated was the proportion of total lane departure crashes that were classified as cross-centerline versus cross-edgeline with respect to traffic volumes. It was expected that cross-edgeline crashes would be more prevalent on the secondary road network due to narrower shoulders and other right-of-way constraints. Figure 38 shows a plot of the percentage of cross-centerline crashes (among total lane departure crashes) versus annual average daily traffic for the secondary network.

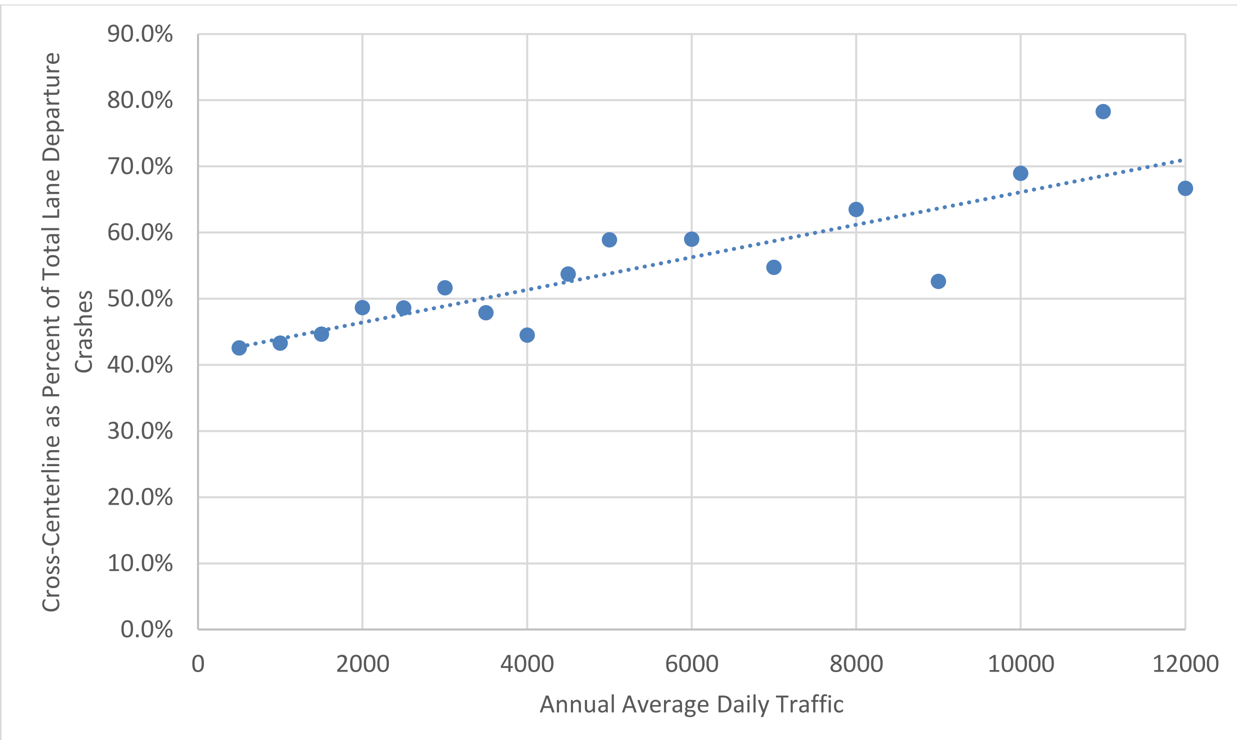


Figure 38. Cross-centerline crashes as a percent of total lane departure crashes on the Iowa secondary highway network versus traffic volume

These data suggest that cross-centerline crashes are more prevalent at higher volumes and that cross-edgeline crashes are more prevalent at lower volumes. However, even in the lowest volume ranges, cross-edgeline events comprise less than 60% of all lane departure crashes. Consequently, from a purely economic standpoint, centerline rumble strips appear to be more cost-effective than edgeline rumble strips. However, given the relatively limited installation of rumble strips on narrow pavements, this is an issue that warrants further investigation as future installations occur.

6.4 Support from Field Studies of Road User Behavior

The results of the crash and economic analyses were supplemented by a series of field studies that examined how drivers vary their lateral position depending on roadway cross-sectional characteristics and the presence or absence of rumble strips. The results of the field studies showed that rumble strips generally reduce the frequency with which drivers deviate from their travel lanes. This suggests that rumble strips are generally effective in providing drivers with feedback that leads to fundamental changes in driving behavior. This improved lane keeping reduces the potential for cross-centerline or cross-edgeline crashes.

A detailed statistical analysis showed that rumble strips and other roadway characteristics also affect encroachment rates. This is somewhat of a concern because it relates to the frequency of incidental contact by motorists under normal driving conditions. In particular, segments with lower posted speed limits, narrower lanes, and paved shoulders and those located along horizontal curves are associated with an increased likelihood of edgeline encroachments. Large vehicles are also more likely to encroach on the centerline or edgeline of the roadway. The probabilities of vehicles encroaching onto either the centerline or edgeline of a roadway under various geometric configurations are summarized in Figure 39 and Figure 40, respectively.

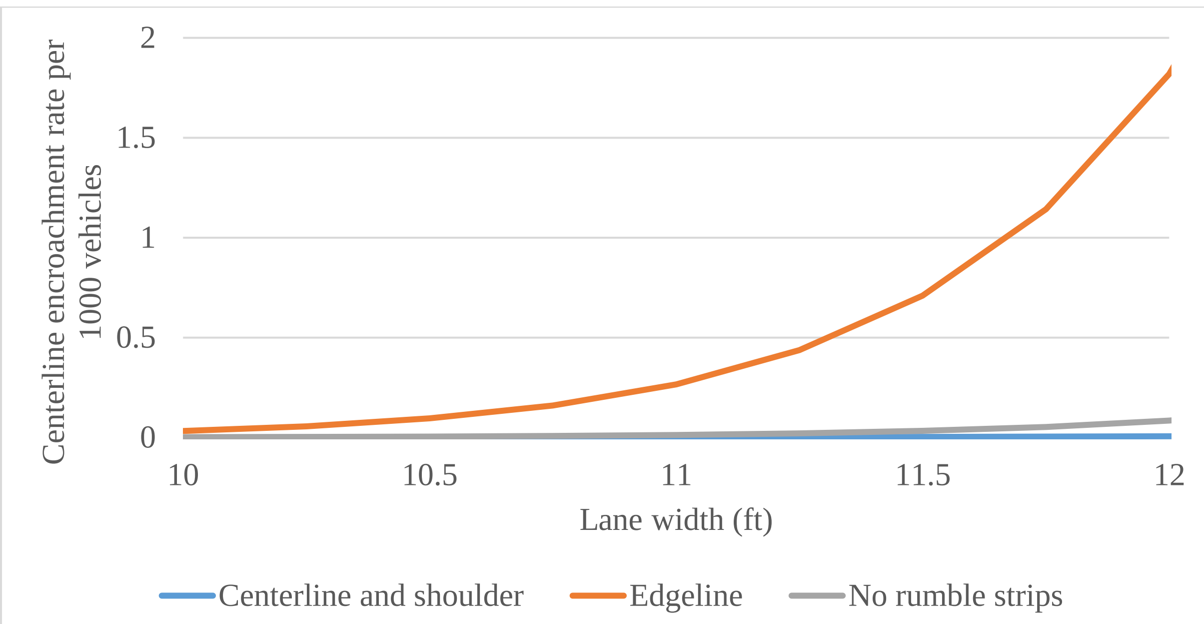


Figure 39. Centerline encroachment probability by rumble strip installation type

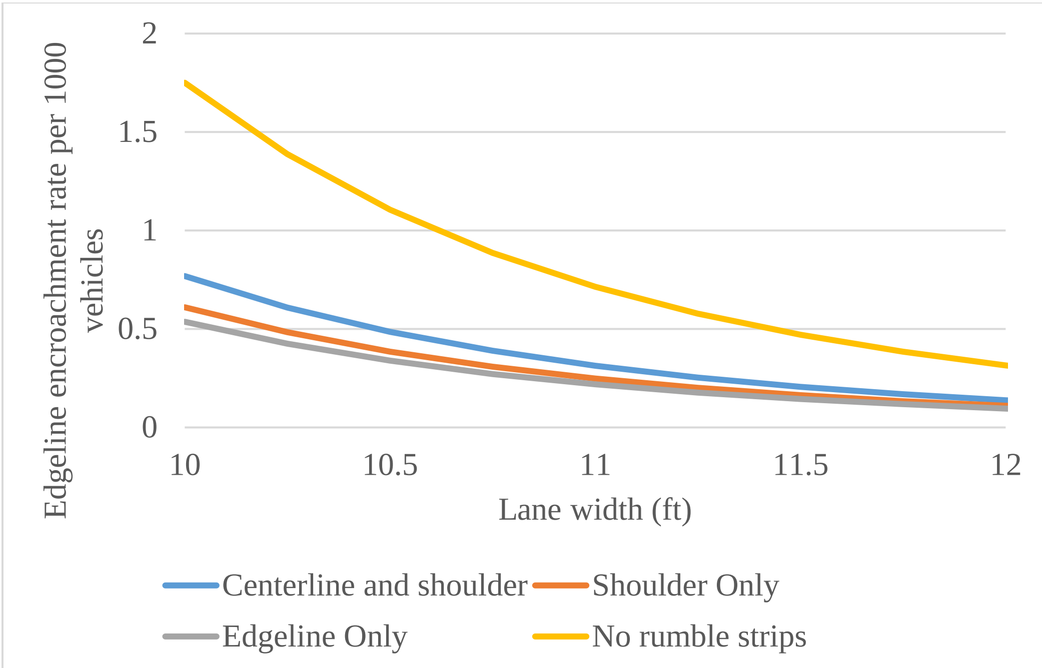


Figure 40. Edgeline encroachment probability by rumble strip installation type

Overall, the probabilities of encroachment are quite small, suggesting that the number of incidental strikes is not a significant concern. Relatedly, the potential noise impacts on nearby residents would also be quite small, except for instances of large volumes of commercial vehicle traffic.

However, the probability of centerline encroachment in instances where edgeline rumble strips are present is a scenario that warrants further explanation. The probability of centerline encroachment increases with an increase in lane width, while the probability of centerline encroachment was found to be elevated in the presence of edgeline rumble strips. Due to the current implementation of rumble strips across the state of Iowa, no 10 ft pavements with edgeline rumble strips were identified. It is likely that centerline encroachment probability on 10 ft lanes with rumble strip installations would be higher than the encroachments estimated in this study. Therefore, it is recommended that rumble strips be installed on the shoulder for these types of facilities.

6.5 Other Rumble Strip Installation Issues

A review of the extant research literature and the results of the road user survey conducted as a part of this study showed that Iowa motorists are generally supportive of rumble strip installations. Rumble strips were found to have minimal adverse impacts on roadway operations, though some respondents indicated concerns regarding noise issues and bicycle safety. These two factors should be considered when determining where to install rumble strips. To this end, the following guidance is provided:

- On roadways that are subject to regular bicycle traffic, a review of national practices suggests that gaps of 10 to 12 ft in length should be provided in cycles of 50 to 60 ft (Ahmed et al. 2015). These gaps will allow bicyclists to safely navigate between the travel lane and the shoulder as necessary. In addition, for those segments with higher bicycle volumes, a minimum paved shoulder width of at least 4 ft is recommended. In instances where this may not be feasible, one alternative would be the installation of narrower edgeline rumble strips or rumble stripes.

- Overall, this research suggests that rumble strips are viable for installation over the vast majority of the two-lane undivided secondary roadway network. In addition to areas with bicyclist concerns, an exception would be those areas with relatively high levels of residential development, where noise may be a great concern. Noise is a particular concern for areas with higher truck volumes.

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APPENDIX A. SUMMARY OF DATA COLLECTION LOCATIONS

PERSONNEL AND EQUIPMENT			
Personnnel	Tim, Trevor, Ellen, Bijan, Abhinav, Skylar	Site Number	1
Trailor	TDC 00162		
Equipment	Wavetronix and LiDAR		

SETUP DETAILS	
Cooridinates	41°53'30.93"N, 93°19'12.28"W
Roadway	IA-210, 320th Street
Nearest Town/City	Collins
Start Time/Date	5/23/2016 11:00
Weather	Cloudy, Windy, Approximately 75 Degrees Farenheit
End Time/Date	5/24/2016 9:30
Weather	Cloudy, 70 Degrees Farenheit, Pavement Edges Wet

MEASUREMENTS

Near Side		
Type	Value	Unit
RS Width	9	Inches
RS Length	17	Inches
RS Spacing	14	Inches
Gravel Shoulder Width	3	Feet
RS to Edge of Pavement	2.42	Feet
RS to Edge Line	0.7	Feet
Edge Line to Edge of Pavement	2.22	Feet
Cardinal Direction	E	
Roadway Direction	EB	

Far Side		
Type	Value	Unit
RS Width	7	Inches
RS Length	17	Inches
RS Spacing	14	Inches
Gravel Shoulder Width	3	Feet
RS to Edge of Pavement	3.42	Feet
RS to Edge Line	0.75	Feet
Edge Line to Edge of Pavement	2.78	Feet
Cardinal Direction	W	
Roadway Direction	WB	

Centerline		
Type	Value	Unit
RS Width	NA	Inches
RS Length	NA	Inches
RS to RS Spacing	NA	Inches
Pair to Pair Spacing	NA	Inches

Trailer		
Type	Value	Unit
To Edge of Pavement	31.5	Feet
To Edgeline	33.72	Feet
To Rumble Strip	33.92	Feet
To Centerline	44.22	Feet

Roadway		
Type	Value	Unit
Edgeline to Edgeline	21	Feet
Edge of Pavement to Edge of Pavement	26	Feet
Rumble Strip to Rumble Strip	21	Feet
Facility Type	2U	
Passing Allowed	Far	
Near Side Posted Speed Limit	55	MPH
Far Side Posted Speed Limit	55	MPH
Segment Type	Tangent	Treatment

SITE SKETCH

PERSONNEL AND EQUIPMENT			
Personnnel	Tim, Trevor, Ellen, Bijan, Abhinav, Skylar	Site Number	2
Trailor	TDC 00164		
Equipment	Wavetronix		

SETUP DETAILS	
Cooridinates	41°52'58.32"N, 93°24'14.26"W
Roadway	IA-210, Main Street
Nearest Town/City	Maxwell
Start Time/Date	5/23/2016 13:30
Weather	Cloudy, Windy, Approximately 75 Degrees Farenheit
End Time/Date	5/23/2016 11:45
Weather	Cloudy, 73 Degrees Farenheit

MEASUREMENTS

Near Side			Centerline		
Type	Value	Unit	Type	Value	Unit
RS Width	6	Inches	RS Width	NA	Inches
RS Length	12	Inches	RS Length	NA	Inches
RS Spacing	13	Inches	RS to RS Spacing	NA	Inches
Gravel Shoulder Width	2	Feet	Pair to Pair Spacing	NA	Inches
RS to Edge of Pavement	3.25	Feet	**Trailer**		
RS to Edge Line	0.75	Feet	Type	Value	Unit
Edge Line to Edge of Pavement	4.25	Feet	To Edge of Pavement	36.5	Feet
Cardinal Direction	SW		To Edgeline	40.75	Feet
Roadway Direction	WB		To Rumble Strip	39.75	Feet
Far Side			To Centerline	52	Feet
Type	Value	Unit	**Roadway**		
RS Width	12	Inches	Type	Value	Unit
RS Length	6	Inches	Edgeline to Edgeline	22.5	Feet
RS Spacing	12	Inches	Edge of Pavement to Edge of Pavement	30.25	Feet
Gravel Shoulder Width	2	Feet	Rumble Strip to Rumble Strip	23.83	Feet
RS to Edge of Pavement	3.17	Feet	Facility Type	2U	
RS to Edge Line	0.5	Feet	Passing Allowed	No	
Edge Line to Edge of Pavement	3.5	Feet	Near Side Posted Speed Limit	55	MPH
Cardinal Direction	NE		Far Side Posted Speed Limit	55	MPH
Roadway Direction	EB		Segment Type	Curve	Treatment

SITE SKETCH

Notes: This site was located just east of a speed transition area where the speed limit dropped to 40 MPH entering the town of Maxwell.

PERSONNEL AND EQUIPMENT			
Personnnel	Grant, Trevor	Site Number	3
Trailor	TDC 00162		
Equipment	Wavetronix		

SETUP DETAILS	
Cooridinates	41°52'41.65"N, 93°24'28.52"W
Roadway	IA-210 West of 650th Ave
Nearest Town/City	Maxwell
Start Time/Date	7/14/2016 15:33
Weather	Sunny
End Time/Date	7/15/2016 11:00
Weather	Sunny

MEASUREMENTS

Near Side		
Type	Value	Unit
RS Width	7	Inches
RS Length	12	Inches
RS Spacing	13	Inches
Gravel Shoulder Width	1.5	Feet
RS to Edge of Pavement	4.33	Feet
RS to Edge Line	0.75	Feet
Edge Line to Edge of Pavement	5.08	Feet
Cardinal Direction	SW	
Roadway Direction	WB	

Far Side		
Type	Value	Unit
RS Width	8	Inches
RS Length	12	Inches
RS Spacing	14	Inches
Gravel Shoulder Width	2.5	Feet
RS to Edge of Pavement	4.25	Feet
RS to Edge Line	0.92	Feet
Edge Line to Edge of Pavement	5.17	Feet
Cardinal Direction	NE	
Roadway Direction	EB	

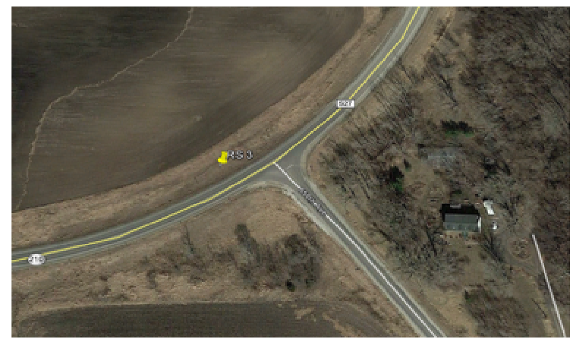
Centerline		
Type	Value	Unit
RS Width	6	Inches
RS Length	16	Inches
RS to RS Spacing	12	Inches
Pair to Pair Spacing	25	Inches

Trailer		
Type	Value	Unit
To Edge of Pavement	28.25	Feet
To Edgeline	33.42	Feet
To Rumble Strip	32.58	Feet
To Centerline	44.33	Feet

Roadway		
Type	Value	Unit
Edgeline to Edgeline	22	Feet
Edge of Pavement to Edge of Pavement	32.33	Feet
Rumble Strip to Rumble Strip	23.67	Feet
Facility Type	2U	
Passing Allowed	No	
Near Side Posted Speed Limit	55	MPH
Far Side Posted Speed Limit	55	MPH
Segment Type	Curve	Treatment

SITE SKETCH

Notes: Chevrons located along the outside of the curve.



PERSONNEL AND EQUIPMENT			
Personnnel	Trevor, Grant	Site Number	4
Trailor	TDC 00164		
Equipment	Wavetronix		

SETUP DETAILS	
Cooridinates	41°52'39.05"N, 93°25'28.86"W
Roadway	IA-210
Nearest Town/City	Maxwell
Start Time/Date	7/14/2016 14:45
Weather	Sunny
End Time/Date	7/15/2016 12:00
Weather	Sunny

MEASUREMENTS

Near Side		
Type	Value	Unit
RS Width	NA	Inches
RS Length	NA	Inches
RS Spacing	NA	Inches
Gravel Shoulder Width	3	Feet
RS to Edge of Pavement	NA	Feet
RS to Edge Line	NA	Feet
Edge Line to Edge of Pavement	2.92	Feet
Cardinal Direction	E	
Roadway Direction	EB	

Far Side		
Type	Value	Unit
RS Width	NA	Inches
RS Length	NA	Inches
RS Spacing	NA	Inches
Gravel Shoulder Width	3	Feet
RS to Edge of Pavement	NA	Feet
RS to Edge Line	NA	Feet
Edge Line to Edge of Pavement	2.67	Feet
Cardinal Direction	W	
Roadway Direction	WB	

Centerline		
Type	Value	Unit
RS Width	NA	Inches
RS Length	NA	Inches
RS to RS Spacing	NA	Inches
Pair to Pair Spacing	NA	Inches

Trailer		
Type	Value	Unit
To Edge of Pavement	27	Feet
To Edgeline	29.75	Feet
To Rumble Strip	NA	Feet
To Centerline	41	Feet

Roadway		
Type	Value	Unit
Edgeline to Edgeline	23	Feet
Edge of Pavement to Edge of Pavement	28	Feet
Rumble Strip to Rumble Strip	NA	Feet
Facility Type	2U	
Passing Allowed	Both	
Near Side Posted Speed Limit	55	MPH
Far Side Posted Speed Limit	55	MPH
Segment Type	Tangent	Control

SITE SKETCH

Notes: This is a control section (no rumble strips present).

PERSONNEL AND EQUIPMENT			
Personnnel	Tim, Trevor, Ellen, Bijan, Abhinav, Skylar	Site Number	5
Trailor	TDC 00162		
Equipment	Wavetronix		

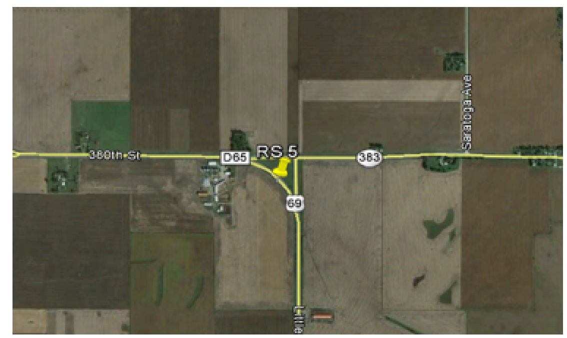
SETUP DETAILS	
Cooridinates	42°14'13.41"N, 93°37'17.70"W
Roadway	US-69 (Little Wall Lake Rd) South of 380th St
Nearest Town/City	Randall
Start Time/Date	5/26/2016 10:20
Weather	Mostly Sunny, 85 Degrees Farenheit
End Time/Date	6/1/2016 8:00
Weather	Sunny

MEASUREMENTS

Near Side			Centerline		
Type	Value	Unit	Type	Value	Unit
RS Width	7	Inches	RS Width	6	Inches
RS Length	12	Inches	RS Length	16	Inches
RS Spacing	13	Inches	RS to RS Spacing	13	Inches
Gravel Shoulder Width	4.5	Feet	Pair to Pair Spacing	38	Inches
RS to Edge of Pavement	3.75	Feet	**Trailer**		
RS to Edge Line	0.92	Feet	Type	Value	Unit
Edge Line to Edge of Pavement	4.42	Feet	To Edge of Pavement	28.5	Feet
Cardinal Direction	SE		To Edgeline	32.92	Feet
Roadway Direction	SB		To Rumble Strip	32	Feet
Far Side			To Centerline	44.5	Feet
Type	Value	Unit	**Roadway**		
RS Width	8	Inches	Type	Value	Unit
RS Length	13	Inches	Edgeline to Edgeline	22.5	Feet
RS Spacing	12	Inches	Edge of Pavement to Edge of Pavement	32.67	Feet
Gravel Shoulder Width	3	Feet	Rumble Strip to Rumble Strip	24.67	Feet
RS to Edge of Pavement	4.16	Feet	Facility Type	2U	
RS to Edge Line	1.16	Feet	Passing Allowed	No	
Edge Line to Edge of Pavement	5.75	Feet	Near Side Posted Speed Limit	55	MPH
Cardinal Direction	NW		Far Side Posted Speed Limit	55	MPH
Roadway Direction	NB		Segment Type	Curve	Treatment

SITE SKETCH

Intermittent rumble strips on shoulders



PERSONNEL AND EQUIPMENT			
Personnnel	Tim, Trevor	Site Number	6
Trailor	TDC 00164		
Equipment	Wavetronix and LiDAR		

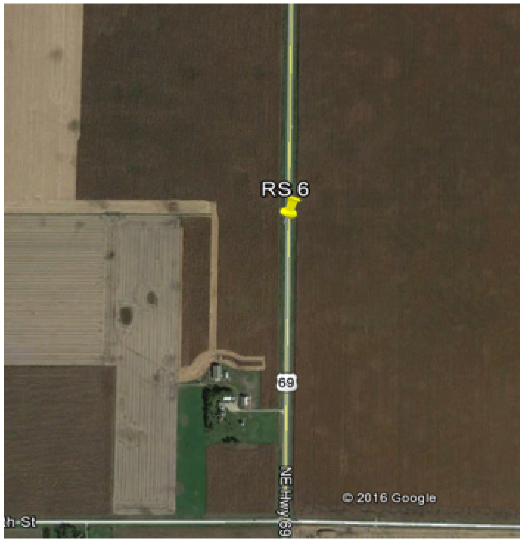
SETUP DETAILS	
Cooridinates	42°12'7.91"N, 93°37'13.41"W
Roadway	US-69 (Little Wall Lake Rd) North of 110th St
Nearest Town/City	Story City
Start Time/Date	5/26/2016 12:30
Weather	Mostly Sunny, 85 Degrees Farenheit
End Time/Date	6/1/2016 9:00
Weather	Sunny

MEASUREMENTS

Near Side			Centerline		
Type	Value	Unit	Type	Value	Unit
RS Width	6	Inches	RS Width	NA	Inches
RS Length	12	Inches	RS Length	NA	Inches
RS Spacing	13	Inches	RS to RS Spacing	NA	Inches
Gravel Shoulder Width	3	Feet	Pair to Pair Spacing	NA	Inches
RS to Edge of Pavement	3.5	Feet	**Trailer**		
RS to Edge Line	0.92	Feet	Type	Value	Unit
Edge Line to Edge of Pavement	4.25	Feet	To Edge of Pavement	25.25	Feet
Cardinal Direction	S		To Edgeline	29.5	Feet
Roadway Direction	SB		To Rumble Strip	28.58	Feet
Far Side			To Centerline	41.33	Feet
Type	Value	Unit	**Roadway**		
RS Width	8	Inches	Type	Value	Unit
RS Length	13	Inches	Edgeline to Edgeline	27.83	Feet
RS Spacing	12	Inches	Edge of Pavement to Edge of Pavement	32.5	Feet
Gravel Shoulder Width	3.5	Feet	Rumble Strip to Rumble Strip	24.75	Feet
RS to Edge of Pavement	4.25	Feet	Facility Type	2U	
RS to Edge Line	1	Feet	Passing Allowed	Both	
Edge Line to Edge of Pavement	0.42	Feet	Near Side Posted Speed Limit	55	MPH
Cardinal Direction	N		Far Side Posted Speed Limit	55	MPH
Roadway Direction	NB		Segment Type	Tangent	Treatment

SITE SKETCH

Intermittent rumble strips, LiDAR located 4.25 feet closer to the road than the Wavetronix



PERSONNEL AND EQUIPMENT			
Personnnel	Tim, Trevor, Bijan, Abhinav	Site Number	7
Trailor	TDC 00164		
Equipment	Wavetronix and LiDAR		

SETUP DETAILS	
Cooridinates	42°10'33.02"N, 93°37'14.51"W
Roadway	US-69
Nearest Town/City	Story City
Start Time/Date	6/1/2016 10:25
Weather	Sunny, 65 Degrees Fahrenheit
End Time/Date	6/2/2016 8:20
Weather	Sunny, 65 Degrees Fahrenheit

MEASUREMENTS

Near Side		
Type	Value	Unit
RS Width	8	Inches
RS Length	14	Inches
RS Spacing	12	Inches
Gravel Shoulder Width	4	Feet
RS to Edge of Pavement	3.58	Feet
RS to Edge Line	0.833	Feet
Edge Line to Edge of Pavement	4.5	Feet
Cardinal Direction	S	
Roadway Direction	SB	
Far Side		
Type	Value	Unit
RS Width	7	Inches
RS Length	14	Inches
RS Spacing	13	Inches
Gravel Shoulder Width	4	Feet
RS to Edge of Pavement	4.1	Feet
RS to Edge Line	1.08	Feet
Edge Line to Edge of Pavement	4.08	Feet
Cardinal Direction	N	
Roadway Direction	NB	

Centerline		
Type	Value	Unit
RS Width	7	Inches
RS Length	16	Inches
RS to RS Spacing	12	Inches
Pair to Pair Spacing	37	Inches
Trailer		
Type	Value	Unit
To Edge of Pavement	27	Feet
To Edgeline	31.42	Feet
To Rumble Strip	30.6	Feet
To Centerline	43.5	Feet
Roadway		
Type	Value	Unit
Edgeline to Edgeline	23.58	Feet
Edge of Pavement to Edge of Pavement	32.17	Feet
Rumble Strip to Rumble Strip	25.33	Feet
Facility Type	2U	
Passing Allowed	Both	
Near Side Posted Speed Limit	55	MPH
Far Side Posted Speed Limit	55	MPH
Segment Type	Tangent	Treatment

SITE SKETCH

Intermittent rumble strips

PERSONNEL AND EQUIPMENT			
Personnnel	Tim, Trevor, Bijan, Abhinav	Site Number	8
Trailor	TDC 00162		
Equipment	Wavetronix		

SETUP DETAILS	
Cooridinates	42° 6'43.85"N, 93°37'14.01"W
Roadway	US-69
Nearest Town/City	Gilbert
Start Time/Date	6/1/2016 12:00
Weather	Sunny, 65 Degrees Farenheit
End Time/Date	6/2/2016 8:30
Weather	Sunny, 65 Degrees Farenheit

MEASUREMENTS

Near Side			Centerline		
Type	Value	Unit	Type	Value	Unit
RS Width	7	Inches	RS Width	6	Inches
RS Length	12	Inches	RS Length	16	Inches
RS Spacing	13	Inches	RS to RS Spacing	13	Inches
Gravel Shoulder Width	2	Feet	Pair to Pair Spacing	36	Inches
RS to Edge of Pavement	5.25	Feet	**Trailer**		
RS to Edge Line	0.83	Feet	Type	Value	Unit
Edge Line to Edge of Pavement	5.83	Feet	To Edge of Pavement	20.58	Feet
Cardinal Direction	S		To Edgeline	26.42	Feet
Roadway Direction	SB		To Rumble Strip	25.58	Feet
Far Side			To Centerline	38	Feet
Type	Value	Unit	**Roadway**		
RS Width	7	Inches	Type	Value	Unit
RS Length	12	Inches	Edgeline to Edgeline	22.83	Feet
RS Spacing	13	Inches	Edge of Pavement to Edge of Pavement	34.33	Feet
Gravel Shoulder Width	2.67	Feet	Rumble Strip to Rumble Strip	24.42	Feet
RS to Edge of Pavement	4.83	Feet	Facility Type	2U	
RS to Edge Line	0.67	Feet	Passing Allowed	Near	
Edge Line to Edge of Pavement	5.67	Feet	Near Side Posted Speed Limit	55	MPH
Cardinal Direction	N		Far Side Posted Speed Limit	55	MPH
Roadway Direction	NB		Segment Type	Tangent	Treatment

SITE SKETCH

Intermittent rumble strips

PERSONNEL AND EQUIPMENT			
Personnnel	Tim, Ellen, Bijan, Abhinav	Site Number	9
Trailor	TDC 00162		
Equipment	Wavetronix		

SETUP DETAILS	
Cooridinates	41°53'2.00"N, 92°53'0.93"W
Roadway	E67 (330th St) West of Taylor Ave
Nearest Town/City	Laurel
Start Time/Date	6/2/2016 10:00
Weather	Sunny, 65 Degrees Farenheit
End Time/Date	6/5/2016 11:00
Weather	Sunny

MEASUREMENTS

Near Side			Centerline		
Type	Value	Unit	Type	Value	Unit
RS Width	NA	Inches	RS Width	NA	Inches
RS Length	NA	Inches	RS Length	NA	Inches
RS Spacing	NA	Inches	RS to RS Spacing	NA	Inches
Gravel Shoulder Width	1	Feet	Pair to Pair Spacing	NA	Inches
RS to Edge of Pavement	3	Feet	**Trailer**		
RS to Edge Line	0.75	Feet	Type	Value	Unit
Edge Line to Edge of Pavement	1.83	Feet	To Edge of Pavement	35.83	Feet
Cardinal Direction	NW		To Edgeline	37.67	Feet
Roadway Direction	WB		To Rumble Strip	36.92	Feet
Far Side			To Centerline	48.42	Feet
Type	Value	Unit	**Roadway**		
RS Width	8	Inches	Type	Value	Unit
RS Length	12	Inches	Edgeline to Edgeline	21.83	Feet
RS Spacing	13	Inches	Edge of Pavement to Edge of Pavement	26.83	Feet
Gravel Shoulder Width	1	Feet	Rumble Strip to Rumble Strip	20.83	Feet
RS to Edge of Pavement	3	Feet	Facility Type	2U	
RS to Edge Line	0.75	Feet	Passing Allowed	No	
Edge Line to Edge of Pavement	3.17	Feet	Near Side Posted Speed Limit	55	MPH
Cardinal Direction	SE		Far Side Posted Speed Limit	55	MPH
Roadway Direction	EB		Segment Type	Curve	Treatment

SITE SKETCH

Intermittent rumble strips on inside of curve only

PERSONNEL AND EQUIPMENT			
Personnnel	Tim, Ellen, Bijan, Abhinav	Site Number	10
Trailor	TDC 00164		
Equipment	Wavetronix and LiDAR		

SETUP DETAILS	
Cooridinates	41°52'48.07"N, 92°52'59.94"W
Roadway	E67 (330th St/Taylor Ave)
Nearest Town/City	Laurel
Start Time/Date	6/2/2016 13:00
Weather	Sunny, 70 degrees Farenheit
End Time/Date	6/5/2016 12:00
Weather	Sunny

MEASUREMENTS

Near Side			Centerline		
Type	Value	Unit	Type	Value	Unit
RS Width	NA	Inches	RS Width	NA	Inches
RS Length	NA	Inches	RS Length	NA	Inches
RS Spacing	NA	Inches	RS to RS Spacing	NA	Inches
Gravel Shoulder Width	1	Feet	Pair to Pair Spacing	NA	Inches
RS to Edge of Pavement	NA	Feet	**Trailer**		
RS to Edge Line	NA	Feet	Type	Value	Unit
Edge Line to Edge of Pavement	1.42	Feet	To Edge of Pavement	14.75	Feet
Cardinal Direction	S		To Edgeline	16.17	Feet
Roadway Direction	EB		To Rumble Strip	NA	Feet
Far Side			To Centerline	26.92	Feet
Type	Value	Unit	**Roadway**		
RS Width	NA	Inches	Type	Value	Unit
RS Length	NA	Inches	Edgeline to Edgeline	21.67	Feet
RS Spacing	NA	Inches	Edge of Pavement to Edge of Pavement	24.17	Feet
Gravel Shoulder Width	2	Feet	Rumble Strip to Rumble Strip	NA	Feet
RS to Edge of Pavement	NA	Feet	Facility Type	2U	
RS to Edge Line	NA	Feet	Passing Allowed	No	
Edge Line to Edge of Pavement	1.08	Feet	Near Side Posted Speed Limit	55	MPH
Cardinal Direction	N		Far Side Posted Speed Limit	55	MPH
Roadway Direction	WB		Segment Type	Tangent	Control

SITE SKETCH

Control section, no rumble strips

PERSONNEL AND EQUIPMENT			
Personnnel	Tim, Bijan, Abhinav	Site Number	11
Trailor	TDC 00164		
Equipment	Wavetronix and LiDAR		

SETUP DETAILS	
Cooridinates	42° 3'11.70"N, 92°49'56.11"W
Roadway	Marshall County E35
Nearest Town/City	Marshalltown
Start Time/Date	6/5/2016 13:00
Weather	Sunny, 70 Degrees Farenheit
End Time/Date	6/9/2016 9:45
Weather	Sunny, 70 Degrees Farenheit

MEASUREMENTS

Near Side		
Type	Value	Unit
RS Width	7	Inches
RS Length	13	Inches
RS Spacing	12	Inches
Gravel Shoulder Width	2.5	Feet
RS to Edge of Pavement	3.83	Feet
RS to Edge Line	0.83	Feet
Edge Line to Edge of Pavement	3.83	Feet
Cardinal Direction	W	
Roadway Direction	WB	

Far Side		
Type	Value	Unit
RS Width	7	Inches
RS Length	13	Inches
RS Spacing	12	Inches
Gravel Shoulder Width	4	Feet
RS to Edge of Pavement	3.5	Feet
RS to Edge Line	0.83	Feet
Edge Line to Edge of Pavement	5.08	Feet
Cardinal Direction	E	
Roadway Direction	EB	

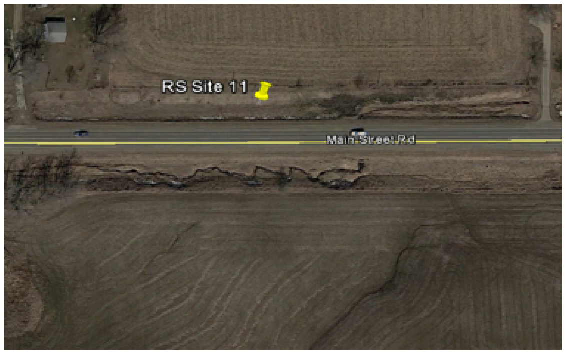
Centerline		
Type	Value	Unit
RS Width	NA	Inches
RS Length	NA	Inches
RS to RS Spacing	NA	Inches
Pair to Pair Spacing	NA	Inches

Trailer		
Type	Value	Unit
To Edge of Pavement	26.17	Feet
To Edgeline	30	Feet
To Rumble Strip	30	Feet
To Centerline	30.75	Feet

Roadway		
Type	Value	Unit
Edgeline to Edgeline	21.42	Feet
Edge of Pavement to Edge of Pavement	30.33	Feet
Rumble Strip to Rumble Strip	23	Feet
Facility Type	2U	
Passing Allowed	Both	
Near Side Posted Speed Limit	55	MPH
Far Side Posted Speed Limit	55	MPH
Segment Type	Tangent	Treatment

SITE SKETCH

Intermittent rumble strips



PERSONNEL AND EQUIPMENT			
Personnnel	Tim, Bijan, Abhinav	Site Number	12
Trailor	TDC 00162		
Equipment	Wavetronix		

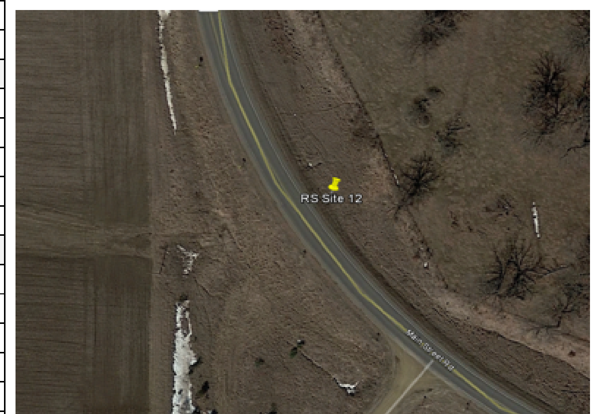
SETUP DETAILS	
Cooridinates	42° 3'1.72"N, 92°49'26.82"W
Roadway	Marshall County E35
Nearest Town/City	Marshalltown
Start Time/Date	6/7/2016 14:00
Weather	Sunny, 70 Degrees Farenheit
End Time/Date	6/8/2016 9:00
Weather	Sunny, 65 Degrees Farenheit

MEASUREMENTS

Near Side			Centerline		
Type	Value	Unit	Type	Value	Unit
RS Width	7	Inches	RS Width	NA	Inches
RS Length	12	Inches	RS Length	NA	Inches
RS Spacing	11	Inches	RS to RS Spacing	NA	Inches
Gravel Shoulder Width	2.5	Feet	Pair to Pair Spacing	NA	Inches
RS to Edge of Pavement	3.42	Feet	**Trailer**		
RS to Edge Line	1.08	Feet	Type	Value	Unit
Edge Line to Edge of Pavement	4.50	Feet	To Edge of Pavement	27.33	Feet
Cardinal Direction	N		To Edgeline	31.83	Feet
Roadway Direction	WB		To Rumble Strip	30.75	Feet
Far Side			To Centerline	42.58	Feet
Type	Value	Unit	**Roadway**		
RS Width	7	Inches	Type	Value	Unit
RS Length	13	Inches	Edgeline to Edgeline	21	Feet
RS Spacing	12	Inches	Edge of Pavement to Edge of Pavement	29.33	Feet
Gravel Shoulder Width	2.5	Feet	Rumble Strip to Rumble Strip	23.75	Feet
RS to Edge of Pavement	3.25	Feet	Facility Type	2U	
RS to Edge Line	1	Feet	Passing Allowed	No	
Edge Line to Edge of Pavement	3.83	Feet	Near Side Posted Speed Limit	55	MPH
Cardinal Direction	S		Far Side Posted Speed Limit	55	MPH
Roadway Direction	EB		Segment Type	Curve	Treatment

SITE SKETCH

Intermittent rumble strips



PERSONNEL AND EQUIPMENT			
Personnnel	Tim, Bijan, Abhinav, Trevor	Site Number	13
Trailor	TDC 00164		
Equipment	Wavetronix and LiDAR		

SETUP DETAILS	
Cooridinates	42° 2'57.77"N, 92°48'49.16"W
Roadway	E35
Nearest Town/City	Marshalltown
Start Time/Date	6/7/2016 10:15
Weather	Sunny, 65 Degrees Fahrenheit
End Time/Date	6/8/2016 8:30
Weather	Sunny, 67 Degrees Fahrenheit

MEASUREMENTS

Near Side			Centerline		
Type	Value	Unit	Type	Value	Unit
RS Width	NA	Inches	RS Width	NA	Inches
RS Length	NA	Inches	RS Length	NA	Inches
RS Spacing	NA	Inches	RS to RS Spacing	NA	Inches
Gravel Shoulder Width	4	Feet	Pair to Pair Spacing	NA	Inches
RS to Edge of Pavement	NA	Feet	**Trailer**		
RS to Edge Line	NA	Feet	Type	Value	Unit
Edge Line to Edge of Pavement	0.75	Feet	To Edge of Pavement	20.08	Feet
Cardinal Direction	E		To Edgeline	20.67	Feet
Roadway Direction	EB		To Rumble Strip	NA	Feet
Far Side			To Centerline	31.42	Feet
Type	Value	Unit	**Roadway**		
RS Width	NA	Inches	Type	Value	Unit
RS Length	NA	Inches	Edgeline to Edgeline	20.75	Feet
RS Spacing	NA	Inches	Edge of Pavement to Edge of Pavement	22.25	Feet
Gravel Shoulder Width	4	Feet	Rumble Strip to Rumble Strip	NA	Feet
RS to Edge of Pavement	NA	Feet	Facility Type	2U	
RS to Edge Line	NA	Feet	Passing Allowed	Both	
Edge Line to Edge of Pavement	0.75	Feet	Near Side Posted Speed Limit	55	MPH
Cardinal Direction	W		Far Side Posted Speed Limit	55	MPH
Roadway Direction	WB		Segment Type	Tangent	Control

SITE SKETCH

Control section, no rumble strips

PERSONNEL AND EQUIPMENT			
Personnnel	Tim, Bijan, Abhinav, Trevor	Site Number	14
Trailor	TDC 00162		
Equipment	Wavetronix		

SETUP DETAILS	
Cooridinates	42° 1'40.58"N, 92°47'2.67"W
Roadway	T-37
Nearest Town/City	Legrand
Start Time/Date	6/7/2016 11:30
Weather	Sunny, 65 Degrees Fahrenheit
End Time/Date	6/8/2016 8:50
Weather	Sunny, 65 Degrees Fahrenheit

MEASUREMENTS

Near Side			Centerline		
Type	Value	Unit	Type	Value	Unit
RS Width	NA	Inches	RS Width	NA	Inches
RS Length	NA	Inches	RS Length	NA	Inches
RS Spacing	NA	Inches	RS to RS Spacing	NA	Inches
Gravel Shoulder Width	5	Feet	Pair to Pair Spacing	NA	Inches
RS to Edge of Pavement	NA	Feet	**Trailer**		
RS to Edge Line	NA	Feet	Type	Value	Unit
Edge Line to Edge of Pavement	0.75	Feet	To Edge of Pavement	28.17	Feet
Cardinal Direction	S		To Edgeline	29	Feet
Roadway Direction	SB		To Rumble Strip	NA	Feet
Far Side			To Centerline	40	Feet
Type	Value	Unit	**Roadway**		
RS Width	NA	Inches	Type	Value	Unit
RS Length	NA	Inches	Edgeline to Edgeline	20.67	Feet
RS Spacing	NA	Inches	Edge of Pavement to Edge of Pavement	22	Feet
Gravel Shoulder Width	4.5	Feet	Rumble Strip to Rumble Strip	NA	Feet
RS to Edge of Pavement	NA	Feet	Facility Type	2U	
RS to Edge Line	NA	Feet	Passing Allowed	No	
Edge Line to Edge of Pavement	0.42	Feet	Near Side Posted Speed Limit	50	MPH
Cardinal Direction	N		Far Side Posted Speed Limit	50	MPH
Roadway Direction	NB		Segment Type	Curve	Control

SITE SKETCH

Control section, no rumble strips

PERSONNEL AND EQUIPMENT			
Personnnel	Tim, Bijan, Abhinav, Trevor	Site Number	15
Trailor	TDC 00162		
Equipment	Wavetronix		

SETUP DETAILS	
Cooridinates	42° 2'57.77"N, 92°48'49.16"W
Roadway	IA-14
Nearest Town/City	Newton
Start Time/Date	6/8/2016 12:00
Weather	Sunny, 65 Degrees Farenheit
End Time/Date	6/9/2016 8:30
Weather	Sunny, 75 Degrees Farenheit

MEASUREMENTS

Near Side		
Type	Value	Unit
RS Width	8	Inches
RS Length	12	Inches
RS Spacing	12	Inches
Gravel Shoulder Width	0.92	Feet
RS to Edge of Pavement	2.17	Feet
RS to Edge Line	0.83	Feet
Edge Line to Edge of Pavement	2	Feet
Cardinal Direction	N	
Roadway Direction	NB	

Far Side		
Type	Value	Unit
RS Width	7	Inches
RS Length	12	Inches
RS Spacing	12	Inches
Gravel Shoulder Width	0.83	Feet
RS to Edge of Pavement	1.83	Feet
RS to Edge Line	0.83	Feet
Edge Line to Edge of Pavement	2.83	Feet
Cardinal Direction	S	
Roadway Direction	SB	

Centerline		
Type	Value	Unit
RS Width	6	Inches
RS Length	11	Inches
RS to RS Spacing	13	Inches
Pair to Pair Spacing	38	Inches

Trailer		
Type	Value	Unit
To Edge of Pavement	61	Feet
To Edgeline	63	Feet
To Rumble Strip	62	Feet
To Centerline	74	Feet

Roadway		
Type	Value	Unit
Edgeline to Edgeline	23.17	Feet
Edge of Pavement to Edge of Pavement	28	Feet
Rumble Strip to Rumble Strip	24.83	Feet
Facility Type	2U	
Passing Allowed	Far	
Near Side Posted Speed Limit	55	MPH
Far Side Posted Speed Limit	55	MPH
Segment Type	Curve	Treatment

SITE SKETCH

Intermittent rumble strips

PERSONNEL AND EQUIPMENT			
Personnnel	Tim, Bijan, Abhinav, Trevor	Site Number	16
Trailor	TDC 00164		
Equipment	Wavetronix and LiDAR		

SETUP DETAILS	
Cooridinates	41°36'4.80"N, 93° 5'47.80"W
Roadway	IA-14, Jasper County
Nearest Town/City	Newton
Start Time/Date	6/7/2016 13:30
Weather	Sunny, 65 Degrees Farenheit
End Time/Date	6/8/2016 8:50
Weather	Sunny, 65 Degrees Farenheit

MEASUREMENTS

Near Side		
Type	Value	Unit
RS Width	6	Inches
RS Length	13	Inches
RS Spacing	12	Inches
Gravel Shoulder Width	1.08	Feet
RS to Edge of Pavement	1.83	Feet
RS to Edge Line	0.83	Feet
Edge Line to Edge of Pavement	2.75	Feet
Cardinal Direction	S	
Roadway Direction	SB	

Far Side		
Type	Value	Unit
RS Width	7	Inches
RS Length	13	Inches
RS Spacing	12	Inches
Gravel Shoulder Width	9	Feet
RS to Edge of Pavement	1.67	Feet
RS to Edge Line	1.17	Feet
Edge Line to Edge of Pavement	2.25	Feet
Cardinal Direction	N	
Roadway Direction	NB	

Centerline		
Type	Value	Unit
RS Width	6	Inches
RS Length	16	Inches
RS to RS Spacing	13	Inches
Pair to Pair Spacing	38	Inches

Trailer		
Type	Value	Unit
To Edge of Pavement	33.5	Feet
To Edgeline	36.25	Feet
To Rumble Strip	35.42	Feet
To Centerline	48	Feet

Roadway		
Type	Value	Unit
Edgeline to Edgeline	23	Feet
Edge of Pavement to Edge of Pavement	28	Feet
Rumble Strip to Rumble Strip	25.75	Feet
Facility Type	2U	
Passing Allowed	Both	
Near Side Posted Speed Limit	55	MPH
Far Side Posted Speed Limit	55	MPH
Segment Type	Tangent	Treatment

SITE SKETCH

Intermittent rumble strips

PERSONNEL AND EQUIPMENT			
Personnnel	Tim, Bijan, Abhinav, Trevor	Site Number	17
Trailor	TDC 00164		
Equipment	Wavetronix and LiDAR		

SETUP DETAILS	
Cooridinates	41°42'9.75"N, 92°58'33.97"W
Roadway	US-6
Nearest Town/City	Newton
Start Time/Date	6/9/2016 10:00
Weather	Sunny, 75 Degrees Farenheit
End Time/Date	6/10/2016 11:00
Weather	Sunny

MEASUREMENTS

Near Side			Centerline		
Type	Value	Unit	Type	Value	Unit
RS Width	6	Inches	RS Width	NA	Inches
RS Length	16	Inches	RS Length	NA	Inches
RS Spacing	13	Inches	RS to RS Spacing	NA	Inches
Gravel Shoulder Width	8	Feet	Pair to Pair Spacing	NA	Inches
RS to Edge of Pavement	3.5	Feet	**Trailer**		
RS to Edge Line	0.75	Feet	Type	Value	Unit
Edge Line to Edge of Pavement	4.33	Feet	To Edge of Pavement	25.33	Feet
Cardinal Direction	E		To Edgeline	29.67	Feet
Roadway Direction	EB		To Rumble Strip	28.92	Feet
Far Side			To Centerline	41.33	Feet
Type	Value	Unit	**Roadway**		
RS Width	5	Inches	Type	Value	Unit
RS Length	15	Inches	Edgeline to Edgeline	23.67	Feet
RS Spacing	9	Inches	Edge of Pavement to Edge of Pavement	32	Feet
Gravel Shoulder Width	6	Feet	Rumble Strip to Rumble Strip	26.75	Feet
RS to Edge of Pavement	3.08	Feet	Facility Type	2U	
RS to Edge Line	0.92	Feet	Passing Allowed	Both	
Edge Line to Edge of Pavement	4.00	Feet	Near Side Posted Speed Limit	55	MPH
Cardinal Direction	W		Far Side Posted Speed Limit	55	MPH
Roadway Direction	WB		Segment Type	Tangent	Treatment

SITE SKETCH

PERSONNEL AND EQUIPMENT			
Personnnel	Tim, Bijan, Abhinav, Trevor	Site Number	18
Trailor	TDC 00162		
Equipment	Wavetronix		

SETUP DETAILS	
Cooridinates	41°42'20.78"N 92°54'37.55"W
Roadway	US-6
Nearest Town/City	Newton
Start Time/Date	6/9/2016 10:30
Weather	Sunny, 75 Degrees Farenheit
End Time/Date	6/10/2016 12:00
Weather	Sunny

MEASUREMENTS

Near Side			Centerline		
Type	Value	Unit	Type	Value	Unit
RS Width	6	Inches	RS Width	NA	Inches
RS Length	16	Inches	RS Length	NA	Inches
RS Spacing	13	Inches	RS to RS Spacing	NA	Inches
Gravel Shoulder Width	7	Feet	Pair to Pair Spacing	NA	Inches
RS to Edge of Pavement	3	Feet	**Trailer**		
RS to Edge Line	1	Feet	Type	Value	Unit
Edge Line to Edge of Pavement	4.33	Feet	To Edge of Pavement	21.58	Feet
Cardinal Direction	E		To Edgeline	25.92	Feet
Roadway Direction	EB		To Rumble Strip	24.33	Feet
Far Side			To Centerline	37.58	Feet
Type	Value	Unit	**Roadway**		
RS Width	6	Inches	Type	Value	Unit
RS Length	15	Inches	Edgeline to Edgeline	22.67	Feet
RS Spacing	13	Inches	Edge of Pavement to Edge of Pavement	31.83	Feet
Gravel Shoulder Width	4	Feet	Rumble Strip to Rumble Strip	25	Feet
RS to Edge of Pavement	4.67	Feet	Facility Type	2U	
RS to Edge Line	1.25	Feet	Passing Allowed	Far	
Edge Line to Edge of Pavement	4.83	Feet	Near Side Posted Speed Limit	55	MPH
Cardinal Direction	W		Far Side Posted Speed Limit	55	MPH
Roadway Direction	WB		Segment Type	Curve	Treatment

SITE SKETCH

PERSONNEL AND EQUIPMENT			
Personnnel	Tim, Bijan, Trevor	Site Number	19
Trailor	TDC 00164		
Equipment	Wavetronix and LiDAR		

SETUP DETAILS	
Cooridinates	41°33'19.74"N, 93°27'58.48"W
Roadway	SE Vandalia Dr
Nearest Town/City	Pleasant Hill
Start Time/Date	6/10/2016 15:00
Weather	Sunny, 90 Degrees Farenheit
End Time/Date	6/12/2016 9:00
Weather	Sunny, 82 Degrees Farenheit

MEASUREMENTS

Near Side

Type	Value	Unit
RS Width	7	Inches
RS Length	5	Inches
RS Spacing	13	Inches
Gravel Shoulder Width	NA	Feet
RS to Edge of Pavement	1.75	Feet
RS to Edge Line	0.75	Feet
Edge Line to Edge of Pavement	2.42	Feet
Cardinal Direction	W	
Roadway Direction	WB	

Far Side

Type	Value	Unit
RS Width	7	Inches
RS Length	5	Inches
RS Spacing	13	Inches
Gravel Shoulder Width	NA	Feet
RS to Edge of Pavement	1.58	Feet
RS to Edge Line	0.83	Feet
Edge Line to Edge of Pavement	1.83	Feet
Cardinal Direction	E	
Roadway Direction	EB	

Centerline

Type	Value	Unit
RS Width	NA	Inches
RS Length	NA	Inches
RS to RS Spacing	NA	Inches
Pair to Pair Spacing	NA	Inches

Trailer

Type	Value	Unit
To Edge of Pavement	22.42	Feet
To Edgeline	24.83	Feet
To Rumble Strip	24.17	Feet
To Centerline	36.5	Feet

Roadway

Type	Value	Unit
Edgeline to Edgeline	23	Feet
Edge of Pavement to Edge of Pavement	27.25	Feet
Rumble Strip to Rumble Strip	24.42	Feet
Facility Type	2U	
Passing Allowed	Far	
Near Side Posted Speed Limit	40	MPH
Far Side Posted Speed Limit	40	MPH
Segment Type	Tangent	Treatment

SITE SKETCH

PERSONNEL AND EQUIPMENT			
Personnnel	Tim, Bijan, Trevor	Site Number	20
Trailor	TDC 00162		
Equipment	Wavetronix		

SETUP DETAILS	
Cooridinates	41°33'25.73"N 93°28'7.66"W
Roadway	SE Vandalia Dr
Nearest Town/City	Pleasant Hill
Start Time/Date	6/10/2016 16:00
Weather	Sunny, 90 Degrees Farenheit
End Time/Date	6/12/2016 9:15
Weather	Sunny, 82 Degrees Farenheit

MEASUREMENTS

Near Side			Centerline		
Type	Value	Unit	Type	Value	Unit
RS Width	6	Inches	RS Width	NA	Inches
RS Length	5	Inches	RS Length	NA	Inches
RS Spacing	13	Inches	RS to RS Spacing	NA	Inches
Gravel Shoulder Width	NA	Feet	Pair to Pair Spacing	NA	Inches
RS to Edge of Pavement	2	Feet	**Trailer**		
RS to Edge Line	0.75	Feet	Type	Value	Unit
Edge Line to Edge of Pavement	2.58	Feet	To Edge of Pavement	20.92	Feet
Cardinal Direction	E		To Edgeline	23.50	Feet
Roadway Direction	EB		To Rumble Strip	22.83	Feet
Far Side			To Centerline	34.83	Feet
Type	Value	Unit	**Roadway**		
RS Width	8	Inches	Type	Value	Unit
RS Length	5	Inches	Edgeline to Edgeline	22.67	Feet
RS Spacing	13	Inches	Edge of Pavement to Edge of Pavement	27.42	Feet
Gravel Shoulder Width	NA	Feet	Rumble Strip to Rumble Strip	24	Feet
RS to Edge of Pavement	1.67	Feet	Facility Type	2U	
RS to Edge Line	0.67	Feet	Passing Allowed	No	
Edge Line to Edge of Pavement	2.17	Feet	Near Side Posted Speed Limit	40	MPH
Cardinal Direction	W		Far Side Posted Speed Limit	40	MPH
Roadway Direction	WB		Segment Type	Curve	Treatment

SITE SKETCH

PERSONNEL AND EQUIPMENT			
Personnnel	Tim, Bijan, Trevor, Abhinav	Site Number	21
Trailor	TDC 00164		
Equipment	Wavetronix and LiDAR		

SETUP DETAILS	
Cooridinates	41°32'11.56"N, 93°26'21.26"W
Roadway	SE Vandalia Dr
Nearest Town/City	Pleasant Hill
Start Time/Date	6/12/2016 10:00
Weather	Sunny, 83 Degrees Farenheit
End Time/Date	6/13/2016 9:00
Weather	Sunny

MEASUREMENTS

Near Side			Centerline		
Type	Value	Unit	Type	Value	Unit
RS Width	NA	Inches	RS Width	NA	Inches
RS Length	NA	Inches	RS Length	NA	Inches
RS Spacing	NA	Inches	RS to RS Spacing	NA	Inches
Gravel Shoulder Width	NA	Feet	Pair to Pair Spacing	NA	Inches
RS to Edge of Pavement	NA	Feet	**Trailer**		
RS to Edge Line	NA	Feet	Type	Value	Unit
Edge Line to Edge of Pavement	3	Feet	To Edge of Pavement	21.92	Feet
Cardinal Direction	NW		To Edgeline	25.08	Feet
Roadway Direction	WB		To Rumble Strip	NA	Feet
Far Side			To Centerline	35.75	Feet
Type	Value	Unit	**Roadway**		
RS Width	NA	Inches	Type	Value	Unit
RS Length	NA	Inches	Edgeline to Edgeline	22.75	Feet
RS Spacing	NA	Inches	Edge of Pavement to Edge of Pavement	28.17	Feet
Gravel Shoulder Width	NA	Feet	Rumble Strip to Rumble Strip	NA	Feet
RS to Edge of Pavement	NA	Feet	Facility Type	2U	
RS to Edge Line	NA	Feet	Passing Allowed	Far	
Edge Line to Edge of Pavement	2.33	Feet	Near Side Posted Speed Limit	55	MPH
Cardinal Direction	SE		Far Side Posted Speed Limit	55	MPH
Roadway Direction	EB		Segment Type	Curve	Control

SITE SKETCH

Intermittent rumble strips

PERSONNEL AND EQUIPMENT			
Personnnel	Tim, Bijan, Trevor, Abhinav	Site Number	22
Trailor	TDC 00164		
Equipment	Wavetronix and LiDAR		

SETUP DETAILS	
Cooridinates	41°32'18.08"N, 93°26'38.86"W
Roadway	F70
Nearest Town/City	Pleasant Hill
Start Time/Date	6/12/2016 11:15
Weather	Sunny, 85 Degrees Farenheit
End Time/Date	6/13/2016 10:00
Weather	Sunny

MEASUREMENTS

Near Side		
Type	Value	Unit
RS Width	NA	Inches
RS Length	NA	Inches
RS Spacing	NA	Inches
Gravel Shoulder Width	NA	Feet
RS to Edge of Pavement	NA	Feet
RS to Edge Line	NA	Feet
Edge Line to Edge of Pavement	2.33	Feet
Cardinal Direction	NW	
Roadway Direction	NWB	

Far Side		
Type	Value	Unit
RS Width	NA	Inches
RS Length	NA	Inches
RS Spacing	NA	Inches
Gravel Shoulder Width	NA	Feet
RS to Edge of Pavement	NA	Feet
RS to Edge Line	NA	Feet
Edge Line to Edge of Pavement	2.42	Feet
Cardinal Direction	SE	
Roadway Direction	SWB	

Centerline		
Type	Value	Unit
RS Width	NA	Inches
RS Length	NA	Inches
RS to RS Spacing	NA	Inches
Pair to Pair Spacing	NA	Inches

Trailer		
Type	Value	Unit
To Edge of Pavement	15.33	Feet
To Edgeline	17.75	Feet
To Rumble Strip	NA	Feet
To Centerline	29.25	Feet

Roadway		
Type	Value	Unit
Edgeline to Edgeline	23.75	Feet
Edge of Pavement to Edge of Pavement	28.25	Feet
Rumble Strip to Rumble Strip	NA	Feet
Facility Type	2U	
Passing Allowed	Near	
Near Side Posted Speed Limit	40	MPH
Far Side Posted Speed Limit	40	MPH
Segment Type	Tangent	Control

SITE SKETCH

PERSONNEL AND EQUIPMENT			
Personnnel	Tim, Bijan, Trevor	Site Number	23
Trailor	TDC 00164		
Equipment	Wavetronix and LiDAR		

SETUP DETAILS	
Cooridinates	41°43'5.37"N, 93°39'46.33"W
Roadway	IA-415
Nearest Town/City	Polk City
Start Time/Date	6/13/2016
Weather	Sunny, 87 Degrees Farenheit
End Time/Date	6/16/2016 9:00
Weather	Sunny

MEASUREMENTS

Near Side			Centerline		
Type	Value	Unit	Type	Value	Unit
RS Width	6	Inches	RS Width	8	Inches
RS Length	13	Inches	RS Length	17	Inches
RS Spacing	1	Inches	RS to RS Spacing	14	Inches
Gravel Shoulder Width	8	Feet	Pair to Pair Spacing	41	Inches
RS to Edge of Pavement	4	Feet	**Trailer**		
RS to Edge Line	1	Feet	Type	Value	Unit
Edge Line to Edge of Pavement	5.08	Feet	To Edge of Pavement	30.83	Feet
Cardinal Direction	N		To Edgeline	35.92	Feet
Roadway Direction	NB		To Rumble Strip	34.83	Feet
Far Side			To Centerline	47.5	Feet
Type	Value	Unit	**Roadway**		
RS Width	6	Inches	Type	Value	Unit
RS Length	12	Inches	Edgeline to Edgeline	24.58	Feet
RS Spacing	12	Inches	Edge of Pavement to Edge of Pavement	31.92	Feet
Gravel Shoulder Width	9	Feet	Rumble Strip to Rumble Strip	22.58	Feet
RS to Edge of Pavement	3.33	Feet	Facility Type	2U	
RS to Edge Line	1.08	Feet	Passing Allowed	Both	
Edge Line to Edge of Pavement	2.25	Feet	Near Side Posted Speed Limit	55	MPH
Cardinal Direction	S		Far Side Posted Speed Limit	55	MPH
Roadway Direction	SB		Segment Type	Tangent	Treatment

SITE SKETCH

PERSONNEL AND EQUIPMENT			
Personnnel	Tim, Bijan, Trevor	Site Number	24
Trailor	TDC 00162		
Equipment	Wavetronix		

SETUP DETAILS	
Cooridinates	41°44'58.83"N, 93°40'48.46"W
Roadway	IA-415
Nearest Town/City	Polk City
Start Time/Date	6/13/2016 13:45
Weather	Sunny, 90 Degrees Farenheit
End Time/Date	6/16/2016 9:30
Weather	Sunny

MEASUREMENTS

Near Side			Centerline		
Type	Value	Unit	Type	Value	Unit
RS Width	6	Inches	RS Width	7	Inches
RS Length	13	Inches	RS Length	16	Inches
RS Spacing	13	Inches	RS to RS Spacing	12	Inches
Gravel Shoulder Width	0.92	Feet	Pair to Pair Spacing	35	Inches
RS to Edge of Pavement	3.67	Feet	**Trailer**		
RS to Edge Line	0.83	Feet	Type	Value	Unit
Edge Line to Edge of Pavement	4.58	Feet	To Edge of Pavement	28.92	Feet
Cardinal Direction	E		To Edgeline	33.50	Feet
Roadway Direction	EB		To Rumble Strip	32.67	Feet
Far Side			To Centerline	45	Feet
Type	Value	Unit	**Roadway**		
RS Width	6	Inches	Type	Value	Unit
RS Length	13	Inches	Edgeline to Edgeline	22.33	Feet
RS Spacing	11	Inches	Edge of Pavement to Edge of Pavement	32.17	Feet
Gravel Shoulder Width	0.83	Feet	Rumble Strip to Rumble Strip	24.17	Feet
RS to Edge of Pavement	4	Feet	Facility Type	2U	
RS to Edge Line	1	Feet	Passing Allowed	Both	
Edge Line to Edge of Pavement	5.25	Feet	Near Side Posted Speed Limit	65	MPH
Cardinal Direction	W		Far Side Posted Speed Limit	55	MPH
Roadway Direction	WB		Segment Type	Curve	Treatment

SITE SKETCH

PERSONNEL AND EQUIPMENT			
Personnnel	Tim, Bijan, Trevor, Abhinav	Site Number	27
Trailor	TDC 00164		
Equipment	Wavetronix and LiDAR		
SETUP DETAILS			
Cooridinates	41°41'18.08"N, 93°50'1.49"W		
Roadway	I-44		
Nearest Town/City	Grimes		
Start Time/Date	6/16/2016 9:50		
Weather	Sunny		
End Time/Date	6/17/2016 9:00		
Weather	Sunny		

MEASUREMENTS

Near Side			Centerline		
Type	Value	Unit	Type	Value	Unit
RS Width	8	Inches	RS Width	7	Inches
RS Length	13	Inches	RS Length	16	Inches
RS Spacing	12	Inches	RS to RS Spacing	11	Inches
Gravel Shoulder Width	8.33	Feet	Pair to Pair Spacing	25	Inches
RS to Edge of Pavement	3.83	Feet	**Trailer**		
RS to Edge Line	0.83	Feet	Type	Value	Unit
Edge Line to Edge of Pavement	4.50	Feet	To Edge of Pavement	28.58	Feet
Cardinal Direction	W		To Edgeline	33.08	Feet
Roadway Direction	WB		To Rumble Strip	32.25	Feet
Far Side			To Centerline	49.5	Feet
Type	Value	Unit	**Roadway**		
RS Width	NA	Inches	Type	Value	Unit
RS Length	NA	Inches	Edgeline to Edgeline	22.75	Feet
RS Spacing	NA	Inches	Edge of Pavement to Edge of Pavement	32	Feet
Gravel Shoulder Width	8.33	Feet	Rumble Strip to Rumble Strip	NA	Feet
RS to Edge of Pavement	NA	Feet	Facility Type	2U	
RS to Edge Line	NA	Feet	Passing Allowed	No	
Edge Line to Edge of Pavement	4.75	Feet	Near Side Posted Speed Limit	50	MPH
Cardinal Direction	E		Far Side Posted Speed Limit	50	MPH
Roadway Direction	EB		Segment Type	Tangent	Treatment

SITE SKETCH

PERSONNEL AND EQUIPMENT			
Personnnel	Tim, Bijan, Trevor, Abhinav	Site Number	28
Trailor	TDC 00162		
Equipment	Wavetronix		

SETUP DETAILS	
Cooridinates	41°41'18.43"N, 94° 3'8.56"W
Roadway	I-44
Nearest Town/City	Dallas City
Start Time/Date	6/16/2016 11:14
Weather	Sunny
End Time/Date	6/17/2016 10:00
Weather	Sunny

MEASUREMENTS

Near Side			Centerline		
Type	Value	Unit	Type	Value	Unit
RS Width	6	Inches	RS Width	NA	Inches
RS Length	14	Inches	RS Length	NA	Inches
RS Spacing	13	Inches	RS to RS Spacing	NA	Inches
Gravel Shoulder Width	4.67	Feet	Pair to Pair Spacing	NA	Inches
RS to Edge of Pavement	1.75	Feet	**Trailer**		
RS to Edge Line	0.92	Feet	Type	Value	Unit
Edge Line to Edge of Pavement	2.33	Feet	To Edge of Pavement	19.92	Feet
Cardinal Direction	E		To Edgeline	22.25	Feet
Roadway Direction	EB		To Rumble Strip	21.67	Feet
Far Side			To Centerline	34	Feet
Type	Value	Unit	**Roadway**		
RS Width	6	Inches	Type	Value	Unit
RS Length	14	Inches	Edgeline to Edgeline	24.5	Feet
RS Spacing	14	Inches	Edge of Pavement to Edge of Pavement	27.92	Feet
Gravel Shoulder Width	5.67	Feet	Rumble Strip to Rumble Strip	22.92	Feet
RS to Edge of Pavement	1.75	Feet	Facility Type	2U	
RS to Edge Line	0.75	Feet	Passing Allowed	No	
Edge Line to Edge of Pavement	1.08	Feet	Near Side Posted Speed Limit	55	MPH
Cardinal Direction	W		Far Side Posted Speed Limit	55	MPH
Roadway Direction	WB		Segment Type	Tangent	Treatment

SITE SKETCH

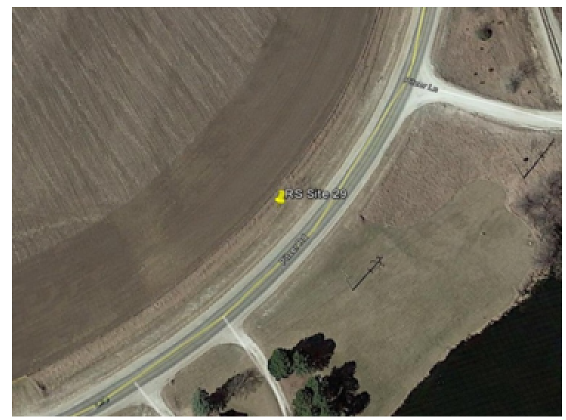
PERSONNEL AND EQUIPMENT			
Personnnel	Grant, Bijan, Trevor, Abhinav	Site Number	29
Trailor	TDC 00162		
Equipment	Wavetronix		

SETUP DETAILS	
Cooridinates	41°30'5.66"N, 94°11'7.80"W
Roadway	P-53
Nearest Town/City	Dexter
Start Time/Date	6/17/2016 11:05
Weather	Sunny
End Time/Date	6/18/2016 9:00
Weather	Sunny

MEASUREMENTS

Near Side			Centerline		
Type	Value	Unit	Type	Value	Unit
RS Width	10	Inches	RS Width	NA	Inches
RS Length	6	Inches	RS Length	NA	Inches
RS Spacing	15	Inches	RS to RS Spacing	NA	Inches
Gravel Shoulder Width	9.33	Feet	Pair to Pair Spacing	NA	Inches
RS to Edge of Pavement	1.67	Feet	**Trailer**		
RS to Edge Line	0.33	Feet	Type	Value	Unit
Edge Line to Edge of Pavement	1	Feet	To Edge of Pavement	31.00	Feet
Cardinal Direction	S		To Edgeline	32.00	Feet
Roadway Direction	SB		To Rumble Strip	31.83	Feet
Far Side			To Centerline	42.17	Feet
Type	Value	Unit	**Roadway**		
RS Width	8	Inches	Type	Value	Unit
RS Length	6	Inches	Edgeline to Edgeline	22.25	Feet
RS Spacing	14	Inches	Edge of Pavement to Edge of Pavement	24	Feet
Gravel Shoulder Width	6.17	Feet	Rumble Strip to Rumble Strip	21.17	Feet
RS to Edge of Pavement	0.75	Feet	Facility Type	2U	
RS to Edge Line	0.25	Feet	Passing Allowed	No	
Edge Line to Edge of Pavement	0.75	Feet	Near Side Posted Speed Limit	55	MPH
Cardinal Direction	N		Far Side Posted Speed Limit	55	MPH
Roadway Direction	NB		Segment Type	Curve	Treatment

SITE SKETCH



PERSONNEL AND EQUIPMENT			
Personnnel	Grant, Bijan, Trevor, Abhinav	Site Number	30
Trailor	TDC 00164		
Equipment	Wavetronix and LiDAR		

SETUP DETAILS	
Cooridinates	41°29'54.26"N, 94°11'6.09"W
Roadway	P-53
Nearest Town/City	Dexter
Start Time/Date	6/17/2016 12:19
Weather	Sunny
End Time/Date	6/18/2016 10:00
Weather	Sunny

MEASUREMENTS

Near Side			Centerline		
Type	Value	Unit	Type	Value	Unit
RS Width	7	Inches	RS Width	NA	Inches
RS Length	6	Inches	RS Length	NA	Inches
RS Spacing	13	Inches	RS to RS Spacing	NA	Inches
Gravel Shoulder Width	9	Feet	Pair to Pair Spacing	NA	Inches
RS to Edge of Pavement	0.92	Feet	**Trailer**		
RS to Edge Line	0	Feet	Type	Value	Unit
Edge Line to Edge of Pavement	0.83	Feet	To Edge of Pavement	35.17	Feet
Cardinal Direction	N		To Edgeline	36	Feet
Roadway Direction	NB		To Rumble Strip	36	Feet
Far Side			To Centerline	45.5	Feet
Type	Value	Unit	**Roadway**		
RS Width	6	Inches	Type	Value	Unit
RS Length	7	Inches	Edgeline to Edgeline	20.5	Feet
RS Spacing	13	Inches	Edge of Pavement to Edge of Pavement	22.08	Feet
Gravel Shoulder Width	7.08	Feet	Rumble Strip to Rumble Strip	20.5	Feet
RS to Edge of Pavement	0.75	Feet	Facility Type	2U	
RS to Edge Line	0	Feet	Passing Allowed	Far	
Edge Line to Edge of Pavement	0.75	Feet	Near Side Posted Speed Limit	55	MPH
Cardinal Direction	S		Far Side Posted Speed Limit	55	MPH
Roadway Direction	SB		Segment Type	Tangent	Treatment

SITE SKETCH

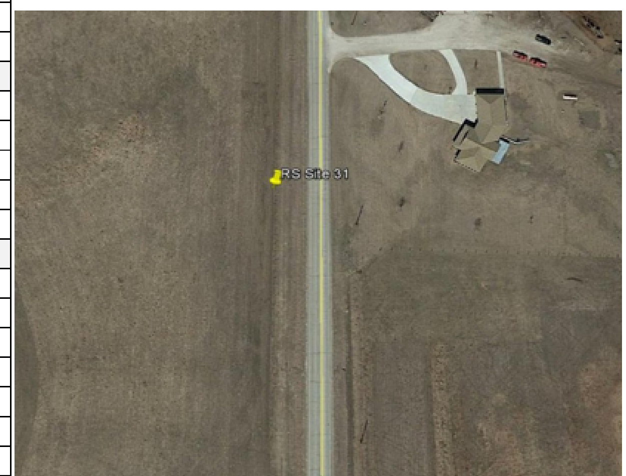
PERSONNEL AND EQUIPMENT			
Personnnel	Ellen, Bijan, Tim	Site Number	31
Trailor	TDC 00164		
Equipment	Wavetronix and LiDAR		

SETUP DETAILS	
Cooridinates	41°16'14.44"N, 94°33'58.89"W
Roadway	N-72
Nearest Town/City	Fontanelle
Start Time/Date	6/18/2016 12:00
Weather	Sunny
End Time/Date	6/20/2016 9:00
Weather	Sunny

MEASUREMENTS

Near Side			Centerline		
Type	Value	Unit	Type	Value	Unit
RS Width	8	Inches	RS Width	NA	Inches
RS Length	12	Inches	RS Length	NA	Inches
RS Spacing	14	Inches	RS to RS Spacing	NA	Inches
Gravel Shoulder Width	1.5	Feet	Pair to Pair Spacing	NA	Inches
RS to Edge of Pavement	1.83	Feet	**Trailer**		
RS to Edge Line	0.75	Feet	Type	Value	Unit
Edge Line to Edge of Pavement	2.67	Feet	To Edge of Pavement	20.83	Feet
Cardinal Direction	S		To Edgeline	23.50	Feet
Roadway Direction	SB		To Rumble Strip	22.75	Feet
Far Side			To Centerline	34.75	Feet
Type	Value	Unit	**Roadway**		
RS Width	8	Inches	Type	Value	Unit
RS Length	12	Inches	Edgeline to Edgeline	22.75	Feet
RS Spacing	14	Inches	Edge of Pavement to Edge of Pavement	26.58	Feet
Gravel Shoulder Width	2	Feet	Rumble Strip to Rumble Strip	21.42	Feet
RS to Edge of Pavement	2	Feet	Facility Type	2U	
RS to Edge Line	0.75	Feet	Passing Allowed	No	
Edge Line to Edge of Pavement	1.16	Feet	Near Side Posted Speed Limit	NA	MPH
Cardinal Direction	N		Far Side Posted Speed Limit	NA	MPH
Roadway Direction	NB		Segment Type	Tangent	Treatment

SITE SKETCH



PERSONNEL AND EQUIPMENT			
Personnnel	Ellen, Bijan, Tim	Site Number	32
Trailor	TDC 00162		
Equipment	Wavetronix		

SETUP DETAILS	
Cooridinates	41°10'41.66"N, 94°33'59.05"W
Roadway	N-72
Nearest Town/City	Orient
Start Time/Date	6/18/2016 14:45
Weather	Sunny
End Time/Date	6/20/2016 10:00
Weather	Sunny

MEASUREMENTS

Near Side			Centerline		
Type	Value	Unit	Type	Value	Unit
RS Width	NA	Inches	RS Width	NA	Inches
RS Length	NA	Inches	RS Length	NA	Inches
RS Spacing	NA	Inches	RS to RS Spacing	NA	Inches
Gravel Shoulder Width	4	Feet	Pair to Pair Spacing	NA	Inches
RS to Edge of Pavement	NA	Feet	**Trailer**		
RS to Edge Line	NA	Feet	Type	Value	Unit
Edge Line to Edge of Pavement	1	Feet	To Edge of Pavement	18.75	Feet
Cardinal Direction	S		To Edgeline	19.25	Feet
Roadway Direction	SB		To Rumble Strip	NA	Feet
Far Side			To Centerline	29.67	Feet
Type	Value	Unit	**Roadway**		
RS Width	NA	Inches	Type	Value	Unit
RS Length	NA	Inches	Edgeline to Edgeline	20.67	Feet
RS Spacing	NA	Inches	Edge of Pavement to Edge of Pavement	22.17	Feet
Gravel Shoulder Width	5	Feet	Rumble Strip to Rumble Strip	NA	Feet
RS to Edge of Pavement	NA	Feet	Facility Type	2U	
RS to Edge Line	NA	Feet	Passing Allowed	Both	
Edge Line to Edge of Pavement	0.5	Feet	Near Side Posted Speed Limit	55	MPH
Cardinal Direction	N		Far Side Posted Speed Limit	55	MPH
Roadway Direction	NB		Segment Type	Tangent	Control

SITE SKETCH

PERSONNEL AND EQUIPMENT			
Personnnel	Ellen, Bijan, Trevor, Abhinav	Site Number	33
Trailor	TDC 00164		
Equipment	Wavetronix and LiDAR		

SETUP DETAILS	
Cooridinates	41°28'48.76"N, 94°38'36.28"W
Roadway	Delta Ave
Nearest Town/City	Adair
Start Time/Date	6/20/2016 11:07
Weather	Cloudy
End Time/Date	6/22/2016 8:00
Weather	Cloudy

MEASUREMENTS

Near Side			Centerline		
Type	Value	Unit	Type	Value	Unit
RS Width	6	Inches	RS Width	NA	Inches
RS Length	12	Inches	RS Length	NA	Inches
RS Spacing	12	Inches	RS to RS Spacing	NA	Inches
Gravel Shoulder Width	1.5	Feet	Pair to Pair Spacing	NA	Inches
RS to Edge of Pavement	2	Feet	**Trailer**		
RS to Edge Line	0.67	Feet	Type	Value	Unit
Edge Line to Edge of Pavement	2.67	Feet	To Edge of Pavement	15.67	Feet
Cardinal Direction	N		To Edgeline	18.33	Feet
Roadway Direction	NB		To Rumble Strip	17.67	Feet
Far Side			To Centerline	29.33	Feet
Type	Value	Unit	**Roadway**		
RS Width	6	Inches	Type	Value	Unit
RS Length	12	Inches	Edgeline to Edgeline	21.42	Feet
RS Spacing	12	Inches	Edge of Pavement to Edge of Pavement	26.83	Feet
Gravel Shoulder Width	3	Feet	Rumble Strip to Rumble Strip	23.25	Feet
RS to Edge of Pavement	1.67	Feet	Facility Type	2U	
RS to Edge Line	1.17	Feet	Passing Allowed	Near	
Edge Line to Edge of Pavement	2.75	Feet	Near Side Posted Speed Limit	55	MPH
Cardinal Direction	S		Far Side Posted Speed Limit	55	MPH
Roadway Direction	SB		Segment Type	Tangent	Treatment

SITE SKETCH

PERSONNEL AND EQUIPMENT			
Personnnel	Ellen, Bijan, Trevor, Abhinav	Site Number	34
Trailor	TDC 00162		
Equipment	Wavetronix		

SETUP DETAILS	
Cooridinates	41°29'1.13"N, 94°40'23.53"W
Roadway	G30
Nearest Town/City	Adair
Start Time/Date	6/20/2016 12:28
Weather	Sunny
End Time/Date	6/22/2016 9:00
Weather	Sunny

MEASUREMENTS

Near Side			Centerline		
Type	Value	Unit	Type	Value	Unit
RS Width	5	Inches	RS Width	NA	Inches
RS Length	12	Inches	RS Length	NA	Inches
RS Spacing	12	Inches	RS to RS Spacing	NA	Inches
Gravel Shoulder Width	1.5	Feet	Pair to Pair Spacing	NA	Inches
RS to Edge of Pavement	2.33	Feet	**Trailer**		
RS to Edge Line	1.25	Feet	Type	Value	Unit
Edge Line to Edge of Pavement	3.50	Feet	To Edge of Pavement	17.58	Feet
Cardinal Direction	E		To Edgeline	21.08	Feet
Roadway Direction	EB		To Rumble Strip	19.83	Feet
Far Side			To Centerline	31.33	Feet
Type	Value	Unit	**Roadway**		
RS Width	7	Inches	Type	Value	Unit
RS Length	12	Inches	Edgeline to Edgeline	21.67	Feet
RS Spacing	12	Inches	Edge of Pavement to Edge of Pavement	28.33	Feet
Gravel Shoulder Width	1	Feet	Rumble Strip to Rumble Strip	23.92	Feet
RS to Edge of Pavement	2.25	Feet	Facility Type	2U	
RS to Edge Line	1	Feet	Passing Allowed	No	
Edge Line to Edge of Pavement	3.16	Feet	Near Side Posted Speed Limit	55	MPH
Cardinal Direction	W		Far Side Posted Speed Limit	55	MPH
Roadway Direction	WB		Segment Type	Curve	Treatment

SITE SKETCH

PERSONNEL AND EQUIPMENT			
Personnnel	Tim, Grant, Trevor, Abhinav	Site Number	35
Trailor	TDC 00164		
Equipment	Wavetronix and LiDAR		

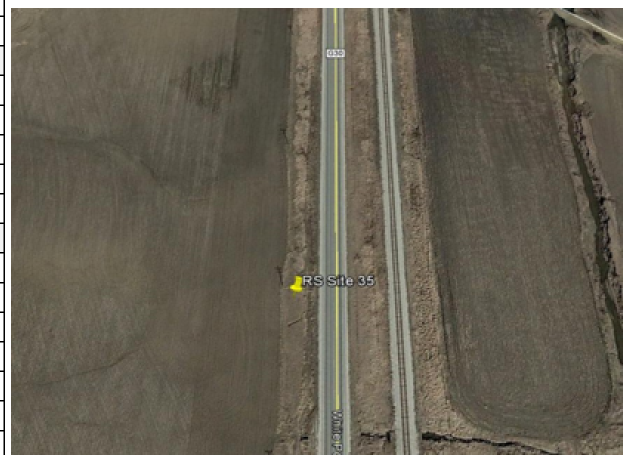
SETUP DETAILS	
Cooridinates	41°28'20.06"N, 94°41'38.14"W
Roadway	G30
Nearest Town/City	Adair
Start Time/Date	6/22/2016 10:55
Weather	Cloudy
End Time/Date	6/23/2016 8:00
Weather	Cloudy

MEASUREMENTS

Near Side			Centerline		
Type	Value	Unit	Type	Value	Unit
RS Width	NA	Inches	RS Width	NA	Inches
RS Length	NA	Inches	RS Length	NA	Inches
RS Spacing	NA	Inches	RS to RS Spacing	NA	Inches
Gravel Shoulder Width	6.67	Feet	Pair to Pair Spacing	NA	Inches
RS to Edge of Pavement	NA	Feet	**Trailer**		
RS to Edge Line	NA	Feet	Type	Value	Unit
Edge Line to Edge of Pavement	1.25	Feet	To Edge of Pavement	33.25	Feet
Cardinal Direction	W		To Edgeline	34.50	Feet
Roadway Direction	WB		To Rumble Strip	NA	Feet
Far Side			To Centerline	45.00	Feet
Type	Value	Unit	**Roadway**		
RS Width	NA	Inches	Type	Value	Unit
RS Length	NA	Inches	Edgeline to Edgeline	22	Feet
RS Spacing	NA	Inches	Edge of Pavement to Edge of Pavement	24.17	Feet
Gravel Shoulder Width	6.50	Feet	Rumble Strip to Rumble Strip	NA	Feet
RS to Edge of Pavement	NA	Feet	Facility Type	2U	
RS to Edge Line	NA	Feet	Passing Allowed	Both	
Edge Line to Edge of Pavement	0.92	Feet	Near Side Posted Speed Limit	55	MPH
Cardinal Direction	E		Far Side Posted Speed Limit	55	MPH
Roadway Direction	EB		Segment Type	Tangent	Control

SITE SKETCH

Control section, no rumble strips



PERSONNEL AND EQUIPMENT			
Personnnel	Tim, Grant, Trevor, Abhinav	Site Number	36
Trailor	TDC 00162		
Equipment	Wavetronix		

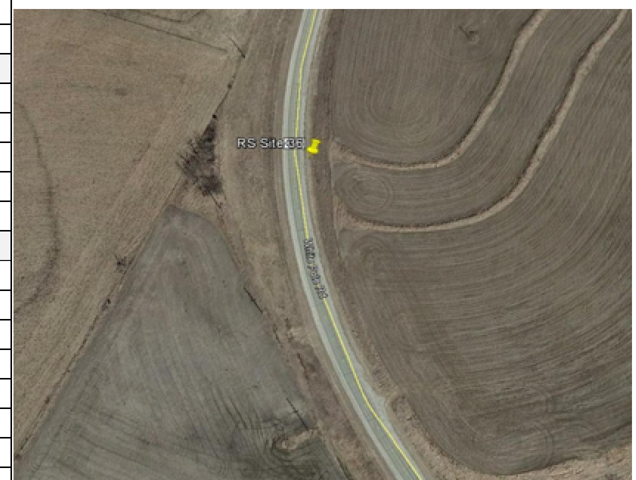
SETUP DETAILS	
Cooridinates	41°27'37.19"N, 94°44'40.96"W
Roadway	G30
Nearest Town/City	Anita
Start Time/Date	6/22/2016 11:50
Weather	Sunny
End Time/Date	6/23/2016 9:00
Weather	Sunny

MEASUREMENTS

Near Side			Centerline		
Type	Value	Unit	Type	Value	Unit
RS Width	NA	Inches	RS Width	NA	Inches
RS Length	NA	Inches	RS Length	NA	Inches
RS Spacing	NA	Inches	RS to RS Spacing	NA	Inches
Gravel Shoulder Width	6.33	Feet	Pair to Pair Spacing	NA	Inches
RS to Edge of Pavement	NA	Feet	**Trailer**		
RS to Edge Line	NA	Feet	Type	Value	Unit
Edge Line to Edge of Pavement	1	Feet	To Edge of Pavement	20.5	Feet
Cardinal Direction	N		To Edgeline	21.5	Feet
Roadway Direction	EB		To Rumble Strip	NA	Feet
Far Side			To Centerline	32.25	Feet
Type	Value	Unit	**Roadway**		
RS Width	NA	Inches	Type	Value	Unit
RS Length	NA	Inches	Edgeline to Edgeline	21.33	Feet
RS Spacing	NA	Inches	Edge of Pavement to Edge of Pavement	24.17	Feet
Gravel Shoulder Width	4.75	Feet	Rumble Strip to Rumble Strip	NA	Feet
RS to Edge of Pavement	NA	Feet	Facility Type	2U	
RS to Edge Line	NA	Feet	Passing Allowed	No	
Edge Line to Edge of Pavement	1.83	Feet	Near Side Posted Speed Limit	55	MPH
Cardinal Direction	S		Far Side Posted Speed Limit	55	MPH
Roadway Direction	WB		Segment Type	Curve	Control

SITE SKETCH

Control Section, no rumble strips



PERSONNEL AND EQUIPMENT			
Personnnel	Tim, Grant, Trevor, Bijan	Site Number	39
Trailor	TDC 00164		
Equipment	Wavetronix and LiDAR		

SETUP DETAILS	
Cooridinates	41°24'1.12"N, 93° 9'42.65"W
Roadway	G40
Nearest Town/City	Pleasantville
Start Time/Date	6/24/2016 13:01
Weather	Sunny
End Time/Date	6/26/2016 8:00
Weather	Sunny

MEASUREMENTS

Near Side			Centerline		
Type	Value	Unit	Type	Value	Unit
RS Width	7	Inches	RS Width	NA	Inches
RS Length	6	Inches	RS Length	NA	Inches
RS Spacing	13	Inches	RS to RS Spacing	NA	Inches
Gravel Shoulder Width	4.67	Feet	Pair to Pair Spacing	NA	Inches
RS to Edge of Pavement	2.25	Feet	**Trailer**		
RS to Edge Line	0	Feet	Type	Value	Unit
Edge Line to Edge of Pavement	2.25	Feet	To Edge of Pavement	17.25	Feet
Cardinal Direction	W		To Edgeline	19.50	Feet
Roadway Direction	WB		To Rumble Strip	19.50	Feet
Far Side			To Centerline	31.42	Feet
Type	Value	Unit	**Roadway**		
RS Width	6	Inches	Type	Value	Unit
RS Length	6	Inches	Edgeline to Edgeline	23.42	Feet
RS Spacing	13	Inches	Edge of Pavement to Edge of Pavement	28.33	Feet
Gravel Shoulder Width	4.58	Feet	Rumble Strip to Rumble Strip	23.08	Feet
RS to Edge of Pavement	2	Feet	Facility Type	2U	
RS to Edge Line	0	Feet	Passing Allowed	Near	
Edge Line to Edge of Pavement	2.67	Feet	Near Side Posted Speed Limit	55	MPH
Cardinal Direction	E		Far Side Posted Speed Limit	55	MPH
Roadway Direction	EB		Segment Type	Tangent	Treatment

SITE SKETCH

PERSONNEL AND EQUIPMENT			
Personnnel	Tim, Grant, Trevor, Bijan	Site Number	40
Trailor	TDC 00162		
Equipment	Wavetronix		

SETUP DETAILS	
Cooridinates	41°24'0.35"N, 93°10'12.47"W
Roadway	G40
Nearest Town/City	Pleasantville
Start Time/Date	6/24/2016 13:34
Weather	Sunny
End Time/Date	6/26/2016 9:00
Weather	Sunny

MEASUREMENTS

Near Side			Centerline		
Type	Value	Unit	Type	Value	Unit
RS Width	NA	Inches	RS Width	NA	Inches
RS Length	NA	Inches	RS Length	NA	Inches
RS Spacing	NA	Inches	RS to RS Spacing	NA	Inches
Gravel Shoulder Width	2.83	Feet	Pair to Pair Spacing	NA	Inches
RS to Edge of Pavement	NA	Feet	**Trailer**		
RS to Edge Line	NA	Feet	Type	Value	Unit
Edge Line to Edge of Pavement	0.75	Feet	To Edge of Pavement	17	Feet
Cardinal Direction	E		To Edgeline	17.75	Feet
Roadway Direction	EB		To Rumble Strip	NA	Feet
Far Side			To Centerline	28.5	Feet
Type	Value	Unit	**Roadway**		
RS Width	NA	Inches	Type	Value	Unit
RS Length	NA	Inches	Edgeline to Edgeline	21.25	Feet
RS Spacing	NA	Inches	Edge of Pavement to Edge of Pavement	22.83	Feet
Gravel Shoulder Width	3.25	Feet	Rumble Strip to Rumble Strip	NA	Feet
RS to Edge of Pavement	NA	Feet	Facility Type	2U	
RS to Edge Line	NA	Feet	Passing Allowed	No	
Edge Line to Edge of Pavement	0.83	Feet	Near Side Posted Speed Limit	55	MPH
Cardinal Direction	W		Far Side Posted Speed Limit	55	MPH
Roadway Direction	WB		Segment Type	Tangent	Control

SITE SKETCH

PERSONNEL AND EQUIPMENT			
Personnnel	Tim, Grant, Trevor, Abhinav	Site Number	41
Trailor	TDC 00164		
Equipment	Wavetronix and LiDAR		

SETUP DETAILS	
Cooridinates	41°23'8.71"N, 93°12'50.72"W
Roadway	G40 Marion
Nearest Town/City	Pleasantville
Start Time/Date	6/23/2016 12:00
Weather	Sunny
End Time/Date	6/24/2016 11:00
Weather	Sunny

MEASUREMENTS

Near Side			Centerline		
Type	Value	Unit	Type	Value	Unit
RS Width	7	Inches	RS Width	NA	Inches
RS Length	7	Inches	RS Length	NA	Inches
RS Spacing	13	Inches	RS to RS Spacing	NA	Inches
Gravel Shoulder Width	5	Feet	Pair to Pair Spacing	NA	Inches
RS to Edge of Pavement	3.33	Feet	**Trailer**		
RS to Edge Line	0.08	Feet	Type	Value	Unit
Edge Line to Edge of Pavement	3.25	Feet	To Edge of Pavement	24.58	Feet
Cardinal Direction	W		To Edgeline	32.83	Feet
Roadway Direction	WB		To Rumble Strip	32.92	Feet
Far Side			To Centerline	44.83	Feet
Type	Value	Unit	**Roadway**		
RS Width	8	Inches	Type	Value	Unit
RS Length	7	Inches	Edgeline to Edgeline	23.42	Feet
RS Spacing	13	Inches	Edge of Pavement to Edge of Pavement	29	Feet
Gravel Shoulder Width	4	Feet	Rumble Strip to Rumble Strip	23.33	Feet
RS to Edge of Pavement	3.33	Feet	Facility Type	2U	
RS to Edge Line	0	Feet	Passing Allowed	Far	
Edge Line to Edge of Pavement	2.33	Feet	Near Side Posted Speed Limit	55	MPH
Cardinal Direction	E		Far Side Posted Speed Limit	55	MPH
Roadway Direction	EB		Segment Type	Tangent	Treatment

SITE SKETCH

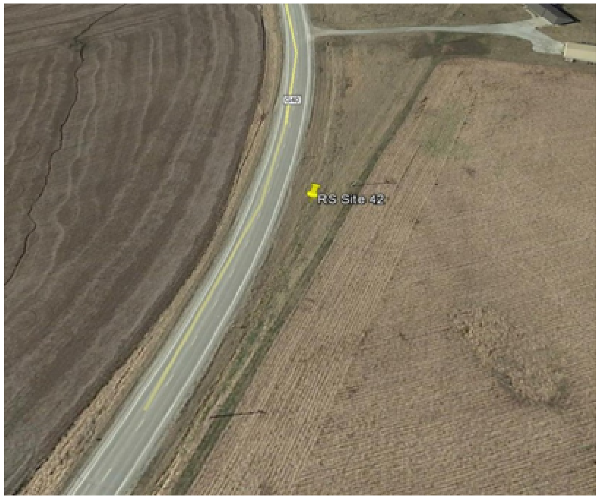
PERSONNEL AND EQUIPMENT			
Personnnel	Tim, Grant, Trevor, Abhinav	Site Number	42
Trailor	TDC 00164		
Equipment	Wavetronix and LiDAR		

SETUP DETAILS	
Cooridinates	41°22'54.29"N, 93°17'33.78"W
Roadway	G40
Nearest Town/City	Pleasantville
Start Time/Date	6/23/2016 12:05
Weather	Cloudy
End Time/Date	6/24/2016 12:00
Weather	Cloudy

MEASUREMENTS

Near Side			Centerline		
Type	Value	Unit	Type	Value	Unit
RS Width	8	Inches	RS Width	NA	Inches
RS Length	7	Inches	RS Length	NA	Inches
RS Spacing	14	Inches	RS to RS Spacing	NA	Inches
Gravel Shoulder Width	3.67	Feet	Pair to Pair Spacing	NA	Inches
RS to Edge of Pavement	4.08	Feet	**Trailer**		
RS to Edge Line	0	Feet	Type	Value	Unit
Edge Line to Edge of Pavement	4.17	Feet	To Edge of Pavement	18.50	Feet
Cardinal Direction	W		To Edgeline	22.67	Feet
Roadway Direction	WB		To Rumble Strip	22.67	Feet
Far Side			To Centerline	35.00	Feet
Type	Value	Unit	**Roadway**		
RS Width	9	Inches	Type	Value	Unit
RS Length	8	Inches	Edgeline to Edgeline	24.08	Feet
RS Spacing	14	Inches	Edge of Pavement to Edge of Pavement	31.67	Feet
Gravel Shoulder Width	6	Feet	Rumble Strip to Rumble Strip	24.83	Feet
RS to Edge of Pavement	3.5	Feet	Facility Type	2U	
RS to Edge Line	0.25	Feet	Passing Allowed	Yes	
Edge Line to Edge of Pavement	3.41	Feet	Near Side Posted Speed Limit	55	MPH
Cardinal Direction	E		Far Side Posted Speed Limit	55	MPH
Roadway Direction	EB		Segment Type	Curve	Treatment

SITE SKETCH



PERSONNEL AND EQUIPMENT			
Personnnel	Tim, Grant, Abhinav	Site Number	43
Trailor	TDC 00162		
Equipment	Wavetronix		
SETUP DETAILS			
Cooridinates	41°25'13.93"N, 93° 3'12.06"W		
Roadway	G28		
Nearest Town/City	Pella		
Start Time/Date	6/26/2016 10:54		
Weather	Cloudy		
End Time/Date	6/27/2016 9:00		
Weather	Cloudy		

MEASUREMENTS

Near Side			Centerline		
Type	Value	Unit	Type	Value	Unit
RS Width	9	Inches	RS Width	NA	Inches
RS Length	7	Inches	RS Length	NA	Inches
RS Spacing	13	Inches	RS to RS Spacing	NA	Inches
Gravel Shoulder Width	8	Feet	Pair to Pair Spacing	NA	Inches
RS to Edge of Pavement	2.83	Feet	**Trailer**		
RS to Edge Line	0.17	Feet	Type	Value	Unit
Edge Line to Edge of Pavement	3.08	Feet	To Edge of Pavement	17.58	Feet
Cardinal Direction	SW		To Edgeline	20.67	Feet
Roadway Direction	WB		To Rumble Strip	20.50	Feet
Far Side			To Centerline	31.42	Feet
Type	Value	Unit	**Roadway**		
RS Width	9	Inches	Type	Value	Unit
RS Length	7	Inches	Edgeline to Edgeline	24	Feet
RS Spacing	13	Inches	Edge of Pavement to Edge of Pavement	28.5	Feet
Gravel Shoulder Width	4	Feet	Rumble Strip to Rumble Strip	24.67	Feet
RS to Edge of Pavement	2.33	Feet	Facility Type	2U	
RS to Edge Line	0	Feet	Passing Allowed	Far	
Edge Line to Edge of Pavement	1.42	Feet	Near Side Posted Speed Limit	55	MPH
Cardinal Direction	NE		Far Side Posted Speed Limit	55	MPH
Roadway Direction	EB		Segment Type	Curve	Treatment

SITE SKETCH

PERSONNEL AND EQUIPMENT			
Personnnel	Tim, Grant, Abhinav	Site Number	44
Trailor	TDC 00164		
Equipment	Wavetronix and LiDAR		

SETUP DETAILS	
Cooridinates	41.4290391, -93.0886126
Roadway	Marion County, G28
Nearest Town/City	Pella
Start Time/Date	6/26/2016 11:40
Weather	Cloudy
End Time/Date	6/27/2016 10:00
Weather	Cloudy

MEASUREMENTS

Near Side			Centerline		
Type	Value	Unit	Type	Value	Unit
RS Width	8	Inches	RS Width	NA	Inches
RS Length	6	Inches	RS Length	NA	Inches
RS Spacing	13	Inches	RS to RS Spacing	NA	Inches
Gravel Shoulder Width	9	Feet	Pair to Pair Spacing	NA	Inches
RS to Edge of Pavement	2	Feet	**Trailer**		
RS to Edge Line	0	Feet	Type	Value	Unit
Edge Line to Edge of Pavement	2.25	Feet	To Edge of Pavement	19.00	Feet
Cardinal Direction	E		To Edgeline	21.25	Feet
Roadway Direction	EB		To Rumble Strip	21.25	Feet
Far Side			To Centerline	33.25	Feet
Type	Value	Unit	**Roadway**		
RS Width	10	Inches	Type	Value	Unit
RS Length	6	Inches	Edgeline to Edgeline	24.00	Feet
RS Spacing	13	Inches	Edge of Pavement to Edge of Pavement	28.58	Feet
Gravel Shoulder Width	9	Feet	Rumble Strip to Rumble Strip	24.00	Feet
RS to Edge of Pavement	2.58	Feet	Facility Type	2U	
RS to Edge Line	0	Feet	Passing Allowed	No	
Edge Line to Edge of Pavement	2.33	Feet	Near Side Posted Speed Limit	NA	MPH
Cardinal Direction	W		Far Side Posted Speed Limit	NA	MPH
Roadway Direction	WB		Segment Type	Tangent	Treatment

SITE SKETCH

PERSONNEL AND EQUIPMENT			
Personnnel	Tim, Grant, Abhinav	Site Number	45
Trailor	TDC 00164		
Equipment	Wavetronix and LiDAR		

SETUP DETAILS	
Cooridinates	41°24'30.44"N, 92°57'25.32"W
Roadway	G28
Nearest Town/City	Pella
Start Time/Date	6/27/2016 11:15
Weather	Sunny
End Time/Date	6/29/2016 7:00
Weather	Sunny

MEASUREMENTS

Near Side			Centerline		
Type	Value	Unit	Type	Value	Unit
RS Width	NA	Inches	RS Width	NA	Inches
RS Length	NA	Inches	RS Length	NA	Inches
RS Spacing	NA	Inches	RS to RS Spacing	NA	Inches
Gravel Shoulder Width	8	Feet	Pair to Pair Spacing	NA	Inches
RS to Edge of Pavement	NA	Feet	**Trailer**		
RS to Edge Line	NA	Feet	Type	Value	Unit
Edge Line to Edge of Pavement	0.5	Feet	To Edge of Pavement	26.75	Feet
Cardinal Direction	W		To Edgeline	27.25	Feet
Roadway Direction	WB		To Rumble Strip	NA	Feet
Far Side			To Centerline	38.5	Feet
Type	Value	Unit	**Roadway**		
RS Width	NA	Inches	Type	Value	Unit
RS Length	NA	Inches	Edgeline to Edgeline	23.17	Feet
RS Spacing	NA	Inches	Edge of Pavement to Edge of Pavement	24	Feet
Gravel Shoulder Width	9	Feet	Rumble Strip to Rumble Strip	NA	Feet
RS to Edge of Pavement	NA	Feet	Facility Type	2U	
RS to Edge Line	NA	Feet	Passing Allowed	Far	
Edge Line to Edge of Pavement	0.67	Feet	Near Side Posted Speed Limit	45	MPH
Cardinal Direction	E		Far Side Posted Speed Limit	45	MPH
Roadway Direction	EB		Segment Type	Tangent	Control

SITE SKETCH

PERSONNEL AND EQUIPMENT			
Personnnel	Tim, Grant, Abhinav	Site Number	46
Trailor	TDC 00162		
Equipment	Wavetronix		

SETUP DETAILS	
Cooridinates	41°25'13.97"N, 93° 2'23.51"W
Roadway	G28
Nearest Town/City	Pella
Start Time/Date	6/27/2016 10:20
Weather	Sunny, 75 Degrees Fahrenheit
End Time/Date	6/29/2016 8:00
Weather	Sunny

MEASUREMENTS

Near Side		
Type	Value	Unit
RS Width	9	Inches
RS Length	7	Inches
RS Spacing	13	Inches
Gravel Shoulder Width	7	Feet
RS to Edge of Pavement	2.58	Feet
RS to Edge Line	0.08	Feet
Edge Line to Edge of Pavement	2.67	Feet
Cardinal Direction	E	
Roadway Direction	EB	

Far Side		
Type	Value	Unit
RS Width	8	Inches
RS Length	7	Inches
RS Spacing	13	Inches
Gravel Shoulder Width	8	Feet
RS to Edge of Pavement	2.25	Feet
RS to Edge Line	0.08	Feet
Edge Line to Edge of Pavement	2.33	Feet
Cardinal Direction	W	
Roadway Direction	WB	

Centerline		
Type	Value	Unit
RS Width	NA	Inches
RS Length	NA	Inches
RS to RS Spacing	NA	Inches
Pair to Pair Spacing	NA	Inches

Trailer		
Type	Value	Unit
To Edge of Pavement	15.42	Feet
To Edgeline	18.08	Feet
To Rumble Strip	18.00	Feet
To Centerline	29.67	Feet

Roadway		
Type	Value	Unit
Edgeline to Edgeline	23.33	Feet
Edge of Pavement to Edge of Pavement	28.33	Feet
Rumble Strip to Rumble Strip	23.33	Feet
Facility Type	2U	
Passing Allowed	Far	
Near Side Posted Speed Limit	55	MPH
Far Side Posted Speed Limit	55	MPH
Segment Type	Curve	Treatment

SITE SKETCH

PERSONNEL AND EQUIPMENT			
Personnnel	Tim, Trevor	Site Number	52
Trailor	TDC 00162		
Equipment	Wavetronix		
SETUP DETAILS			
Cooridinates	42°25'1.23"N, 91°46'53.22"W		
Roadway	W35		
Nearest Town/City	Independence		
Start Time/Date	7/8/2016 17:09		
Weather	Sunny		
End Time/Date	7/9/2016 14:00		
Weather	Sunny		

MEASUREMENTS

Near Side			Centerline			SITE SKETCH
Type	Value	Unit	Type	Value	Unit	
RS Width	NA	Inches	RS Width	6	Inches	
RS Length	NA	Inches	RS Length	6	Inches	
RS Spacing	NA	Inches	RS to RS Spacing	13	Inches	
Gravel Shoulder Width	4	Feet	Pair to Pair Spacing	NA	Inches	
RS to Edge of Pavement	NA	Feet	**Trailer**			
RS to Edge Line	NA	Feet	Type	Value	Unit	
Edge Line to Edge of Pavement	0.75	Feet	To Edge of Pavement	17.95	Feet	
Cardinal Direction	S		To Edgeline	18.17	Feet	
Roadway Direction	EB		To Rumble Strip	NA	Feet	
Far Side			To Centerline	28.25	Feet	
Type	Value	Unit	**Roadway**			
RS Width	NA	Inches	Type	Value	Unit	
RS Length	NA	Inches	Edgeline to Edgeline	20.5	Feet	
RS Spacing	NA	Inches	Edge of Pavement to Edge of Pavement	22	Feet	
Gravel Shoulder Width	4	Feet	Rumble Strip to Rumble Strip	NA	Feet	
RS to Edge of Pavement	NA	Feet	Facility Type	2U		
RS to Edge Line	NA	Feet	Passing Allowed	No		
Edge Line to Edge of Pavement	0.67	Feet	Near Side Posted Speed Limit	45	MPH	
Cardinal Direction	N		Far Side Posted Speed Limit	45	MPH	
Roadway Direction	WB		Segment Type	Curve	Treatment	

PERSONNEL AND EQUIPMENT

Personnnel	Tim, Trevor	Site Number	53
Trailor	TDC 00164		
Equipment	Wavetronix		

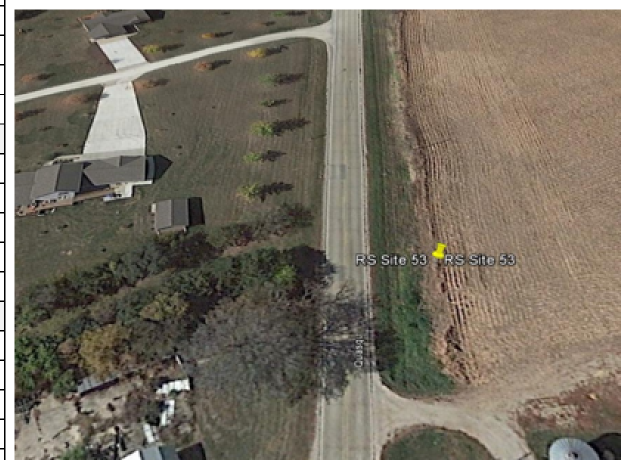
SETUP DETAILS

Cooridinates	42°24'40.87"N, 91°45'57.65"W
Roadway	W35
Nearest Town/City	Independence
Start Time/Date	7/8/2016 18:11
Weather	Sunny
End Time/Date	7/9/2016 15:00
Weather	Sunny

MEASUREMENTS

Near Side			Centerline		
Type	Value	Unit	Type	Value	Unit
RS Width	NA	Inches	RS Width	9	Inches
RS Length	NA	Inches	RS Length	7	Inches
RS Spacing	NA	Inches	RS to RS Spacing	14	Inches
Gravel Shoulder Width	3	Feet	Pair to Pair Spacing	NA	Inches
RS to Edge of Pavement	NA	Feet	**Trailer**		
RS to Edge Line	NA	Feet	Type	Value	Unit
Edge Line to Edge of Pavement	0.67	Feet	To Edge of Pavement	22.25	Feet
Cardinal Direction	N		To Edgeline	23.00	Feet
Roadway Direction	NB		To Rumble Strip	NA	Feet
Far Side			To Centerline	33.42	Feet
Type	Value	Unit	**Roadway**		
RS Width	NA	Inches	Type	Value	Unit
RS Length	NA	Inches	Edgeline to Edgeline	20.75	Feet
RS Spacing	NA	Inches	Edge of Pavement to Edge of Pavement	22.08	Feet
Gravel Shoulder Width	4	Feet	Rumble Strip to Rumble Strip	NA	Feet
RS to Edge of Pavement	NA	Feet	Facility Type	2U	
RS to Edge Line	NA	Feet	Passing Allowed	Near	
Edge Line to Edge of Pavement	0.5	Feet	Near Side Posted Speed Limit	45	MPH
Cardinal Direction	S		Far Side Posted Speed Limit	45	MPH
Roadway Direction	SB		Segment Type	Tangent	Treatment

SITE SKETCH



PERSONNEL AND EQUIPMENT			
Personnnel	Tim, Trevor	Site Number	55
Trailor	TDC 00162		
Equipment	Wavetronix		

SETUP DETAILS	
Cooridinates	42°25'58.56"N, 91°49'4.04"W
Roadway	W35
Nearest Town/City	Independence
Start Time/Date	7/9/2016 16:02
Weather	Sunny
End Time/Date	7/10/2016 12:00
Weather	Sunny

MEASUREMENTS

Near Side			Centerline		
Type	Value	Unit	Type	Value	Unit
RS Width	NA	Inches	RS Width	6	Inches
RS Length	NA	Inches	RS Length	6	Inches
RS Spacing	NA	Inches	RS to RS Spacing	13	Inches
Gravel Shoulder Width	3	Feet	Pair to Pair Spacing	NA	Inches
RS to Edge of Pavement	NA	Feet	**Trailer**		
RS to Edge Line	NA	Feet	Type	Value	Unit
Edge Line to Edge of Pavement	0.58	Feet	To Edge of Pavement	19.42	Feet
Cardinal Direction	W		To Edgeline	20.17	Feet
Roadway Direction	NB		To Rumble Strip	NA	Feet
Far Side			To Centerline	30.83	Feet
Type	Value	Unit	**Roadway**		
RS Width	NA	Inches	Type	Value	Unit
RS Length	NA	Inches	Edgeline to Edgeline	20.83	Feet
RS Spacing	NA	Inches	Edge of Pavement to Edge of Pavement	22.08	Feet
Gravel Shoulder Width	5.5	Feet	Rumble Strip to Rumble Strip	NA	Feet
RS to Edge of Pavement	NA	Feet	Facility Type	2U	
RS to Edge Line	NA	Feet	Passing Allowed	Near	
Edge Line to Edge of Pavement	0.75	Feet	Near Side Posted Speed Limit	45	MPH
Cardinal Direction	E		Far Side Posted Speed Limit	45	MPH
Roadway Direction	SB		Segment Type	Curve	Treatment

SITE SKETCH

PERSONNEL AND EQUIPMENT			
Personnnel	Tim, Trevor	Site Number	56
Trailor	TDC 00164		
Equipment	Wavetronix		

SETUP DETAILS	
Cooridinates	42°27'39.49"N, 91°50'52.79"W
Roadway	W35
Nearest Town/City	Independence
Start Time/Date	7/9/2016 16:42
Weather	Sunny
End Time/Date	7/11/2016 10:00
Weather	Sunny

MEASUREMENTS

Near Side			Centerline		
Type	Value	Unit	Type	Value	Unit
RS Width	NA	Inches	RS Width	7	Inches
RS Length	NA	Inches	RS Length	6	Inches
RS Spacing	NA	Inches	RS to RS Spacing	13	Inches
Gravel Shoulder Width	5	Feet	Pair to Pair Spacing	NA	Inches
RS to Edge of Pavement	NA	Feet	**Trailer**		
RS to Edge Line	NA	Feet	Type	Value	Unit
Edge Line to Edge of Pavement	0.83	Feet	To Edge of Pavement	18.25	Feet
Cardinal Direction	N		To Edgeline	19.08	Feet
Roadway Direction	NB		To Rumble Strip	NA	Feet
Far Side			To Centerline	29.42	Feet
Type	Value	Unit	**Roadway**		
RS Width	NA	Inches	Type	Value	Unit
RS Length	NA	Inches	Edgeline to Edgeline	20.67	Feet
RS Spacing	NA	Inches	Edge of Pavement to Edge of Pavement	22.08	Feet
Gravel Shoulder Width	4.5	Feet	Rumble Strip to Rumble Strip	NA	Feet
RS to Edge of Pavement	NA	Feet	Facility Type	2U	
RS to Edge Line	NA	Feet	Passing Allowed	Near	
Edge Line to Edge of Pavement	0.83	Feet	Near Side Posted Speed Limit	45	MPH
Cardinal Direction	S		Far Side Posted Speed Limit	45	MPH
Roadway Direction	SB		Segment Type	Tangent	Treatment

SITE SKETCH

PERSONNEL AND EQUIPMENT			
Personnnel	Trevor, Tim	Site Number	57
Trailor	TDC 00162		
Equipment	Wavetronix		

SETUP DETAILS	
Cooridinates	42°31'24.74"N, 91°58'13.62"W
Roadway	D16
Nearest Town/City	Independence
Start Time/Date	7/10/2016 14:55
Weather	Rain
End Time/Date	7/11/2016 11:00
Weather	Sunny

MEASUREMENTS

Near Side			Centerline		
Type	Value	Unit	Type	Value	Unit
RS Width	9	Inches	RS Width	NA	Inches
RS Length	5	Inches	RS Length	NA	Inches
RS Spacing	14	Inches	RS to RS Spacing	NA	Inches
Gravel Shoulder Width	6.5	Feet	Pair to Pair Spacing	NA	Inches
RS to Edge of Pavement	8	Feet	**Trailer**		
RS to Edge Line	0	Feet	Type	Value	Unit
Edge Line to Edge of Pavement	8	Feet	To Edge of Pavement	27.75	Feet
Cardinal Direction	N		To Edgeline	28.33	Feet
Roadway Direction	NB		To Rumble Strip	28.33	Feet
Far Side			To Centerline	38.83	Feet
Type	Value	Unit	**Roadway**		
RS Width	7	Inches	Type	Value	Unit
RS Length	5	Inches	Edgeline to Edgeline	20.33	Feet
RS Spacing	12	Inches	Edge of Pavement to Edge of Pavement	22	Feet
Gravel Shoulder Width	6	Feet	Rumble Strip to Rumble Strip	20.5	Feet
RS to Edge of Pavement	1	Feet	Facility Type	2U	
RS to Edge Line	0.17	Feet	Passing Allowed	Both	
Edge Line to Edge of Pavement	1.17	Feet	Near Side Posted Speed Limit	55	MPH
Cardinal Direction	S		Far Side Posted Speed Limit	55	MPH
Roadway Direction	SB		Segment Type	Curve	Treatment

SITE SKETCH

PERSONNEL AND EQUIPMENT			
Personnnel	Grant, Tim, Abhinav	Site Number	59
Trailor	TDC 00164		
Equipment	Wavetronix		

SETUP DETAILS	
Cooridinates	41°47'13.02"N, 91°14'31.40"W
Roadway	F28, Cedar County
Nearest Town/City	Tipton
Start Time/Date	6/29/2016 10:00
Weather	Sunny
End Time/Date	6/30/2016 9:00
Weather	Sunny

MEASUREMENTS

Near Side			Centerline		
Type	Value	Unit	Type	Value	Unit
RS Width	NA	Inches	RS Width	NA	Inches
RS Length	NA	Inches	RS Length	NA	Inches
RS Spacing	NA	Inches	RS to RS Spacing	NA	Inches
Gravel Shoulder Width	7	Feet	Pair to Pair Spacing	NA	Inches
RS to Edge of Pavement	NA	Feet	**Trailer**		
RS to Edge Line	NA	Feet	Type	Value	Unit
Edge Line to Edge of Pavement	0.65	Feet	To Edge of Pavement	27.58	Feet
Cardinal Direction	E		To Edgeline	28.25	Feet
Roadway Direction	EB		To Rumble Strip	NA	Feet
Far Side			To Centerline	39.5	Feet
Type	Value	Unit	**Roadway**		
RS Width	NA	Inches	Type	Value	Unit
RS Length	NA	Inches	Edgeline to Edgeline	22.7	Feet
RS Spacing	NA	Inches	Edge of Pavement to Edge of Pavement	29	Feet
Gravel Shoulder Width	7	Feet	Rumble Strip to Rumble Strip	NA	Feet
RS to Edge of Pavement	NA	Feet	Facility Type	2U	
RS to Edge Line	NA	Feet	Passing Allowed	Both	
Edge Line to Edge of Pavement	0.7	Feet	Near Side Posted Speed Limit	55	MPH
Cardinal Direction	W		Far Side Posted Speed Limit	55	MPH
Roadway Direction	WB		Segment Type	Tangent	Control

SITE SKETCH

Control

PERSONNEL AND EQUIPMENT			
Personnel	Grant, Tim, Abhinav	Site Number	60
Trailor	TDC 00162		
Equipment	Wavetronix		

SETUP DETAILS	
Cooridinates	41°47'10.31"N, 91°10'38.92"W
Roadway	F28
Nearest Town/City	Tipton
Start Time/Date	6/29/2016 9:00
Weather	Sunny
End Time/Date	6/30/2016 10:00
Weather	Sunny

MEASUREMENTS

Near Side		
Type	Value	Unit
RS Width	8	Inches
RS Length	12	Inches
RS Spacing	13	Inches
Gravel Shoulder Width	3	Feet
RS to Edge of Pavement	4.5	Feet
RS to Edge Line	0.83	Feet
Edge Line to Edge of Pavement	5.25	Feet
Cardinal Direction	E	
Roadway Direction	EB	

Far Side		
Type	Value	Unit
RS Width	8	Inches
RS Length	13	Inches
RS Spacing	13	Inches
Gravel Shoulder Width	3	Feet
RS to Edge of Pavement	4	Feet
RS to Edge Line	1	Feet
Edge Line to Edge of Pavement	5	Feet
Cardinal Direction	W	
Roadway Direction	WB	

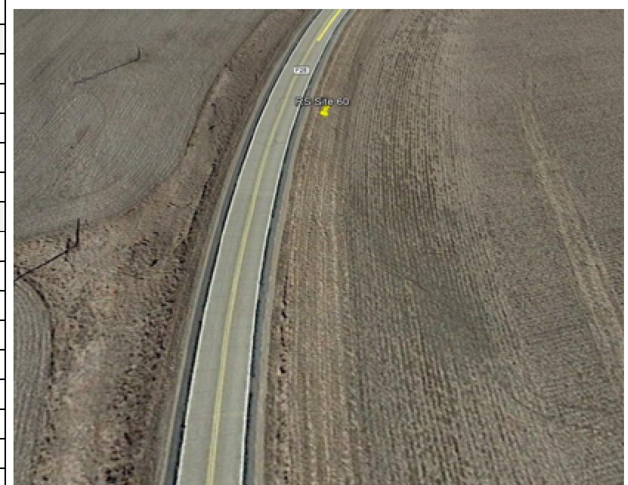
Centerline		
Type	Value	Unit
RS Width	NA	Inches
RS Length	NA	Inches
RS to RS Spacing	NA	Inches
Pair to Pair Spacing	NA	Inches

Trailer		
Type	Value	Unit
To Edge of Pavement	16.83	Feet
To Edgeline	22	Feet
To Rumble Strip	21.25	Feet
To Centerline	33	Feet

Roadway		
Type	Value	Unit
Edgeline to Edgeline	22.5	Feet
Edge of Pavement to Edge of Pavement	32.25	Feet
Rumble Strip to Rumble Strip	24.33	Feet
Facility Type	2U	
Passing Allowed	No	
Near Side Posted Speed Limit	55	MPH
Far Side Posted Speed Limit	55	MPH
Segment Type	Curve	Treatment

SITE SKETCH

Concrete road with asphalt on the outside. The edgeline on concrete, rumble strip on asphalt. Slight gravel shoulder. Near side, conc width=4.5', far side conc width=4.25'. EOP-EOP roadway measurement includes conc & asphalt, just edge of concrete-edge of concrete = 24'



PERSONNEL AND EQUIPMENT			
Personnnel	Grant, Trevor, Bijan	Site Number	61
Trailor	TDC 00164		
Equipment	Wavetronix		

SETUP DETAILS	
Cooridinates	41°54'43.40"N, 90°31'42.93"W
Roadway	Z2E
Nearest Town/City	Charlotte
Start Time/Date	7/6/2016 11:15
Weather	Cloudy
End Time/Date	7/8/2016 11:00
Weather	Cloudy

MEASUREMENTS

Near Side

Type	Value	Unit
RS Width	8	Inches
RS Length	4	Inches
RS Spacing	13	Inches
Gravel Shoulder Width	4	Feet
RS to Edge of Pavement	3.5	Feet
RS to Edge Line	0.08	Feet
Edge Line to Edge of Pavement	3.42	feet
Cardinal Direction	E	
Roadway Direction	NB	

Far Side

Type	Value	Unit
RS Width	8	Inches
RS Length	4	Inches
RS Spacing	13	Inches
Gravel Shoulder Width	4	Feet
RS to Edge of Pavement	3.75	Feet
RS to Edge Line	0.17	Feet
Edge Line to Edge of Pavement	3.58	feet
Cardinal Direction	W	
Roadway Direction	SB	

Centerline

Type	Value	Unit
RS Width	NA	Inches
RS Length	NA	Inches
RS to RS Spacing	NA	Inches
Pair to Pair Spacing	NA	Inches

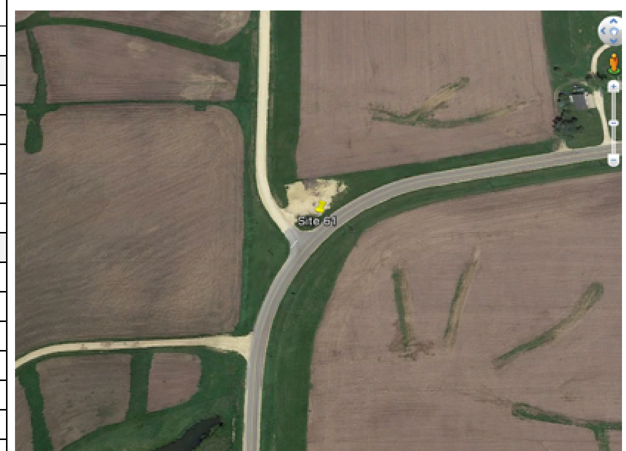
Trailer

Type	Value	Unit
To Edge of Pavement	14.5	Feet
To Edgeline	17.92	Feet
To Rumble Strip	18	Feet
To Centerline	29	Feet

Roadway

Type	Value	Unit
Edgeline to Edgeline	22.25	Feet
Edge of Pavement to Edge of Pavement	28.83	Feet
Rumble Strip to Rumble Strip	21.83	Feet
Facility Type	2U	
Passing Allowed	No	
Near Side Posted Speed Limit	55	MPH
Far Side Posted Speed Limit	55	MPH
Segment Type	Curve	Treatment

SITE SKETCH



PERSONNEL AND EQUIPMENT			
Personnnel	Grant, Trevor, Bijan	Site Number	62
Trailor	TDC 00162		
Equipment	Wavetronix		

SETUP DETAILS	
Cooridinates	41°56'38.76"N, 90°30'14.81"W
Roadway	Z2E
Nearest Town/City	Charlotte
Start Time/Date	7/6/2016 12:30
Weather	Cloudy
End Time/Date	7/8/2016 12:00
Weather	Cloudy

MEASUREMENTS

Near Side			Centerline		
Type	Value	Unit	Type	Value	Unit
RS Width	6	Inches	RS Width	NA	Inches
RS Length	16	Inches	RS Length	NA	Inches
RS Spacing	12	Inches	RS to RS Spacing	NA	Inches
Gravel Shoulder Width	NA	Feet	Pair to Pair Spacing	NA	Inches
RS to Edge of Pavement	4.25	Feet	**Trailer**		
RS to Edge Line	2.17	Feet	Type	Value	Unit
Edge Line to Edge of Pavement	6.33	Feet	To Edge of Pavement	12.33	Feet
Cardinal Direction	E		To Edgeline	18.5	Feet
Roadway Direction	NB		To Rumble Strip	16.5	Feet
Far Side			To Centerline	29.5	Feet
Type	Value	Unit	**Roadway**		
RS Width	5	Inches	Type	Value	Unit
RS Length	16	Inches	Edgeline to Edgeline	21.5	Feet
RS Spacing	12	Inches	Edge of Pavement to Edge of Pavement	33.92	Feet
Gravel Shoulder Width	NA	Feet	Rumble Strip to Rumble Strip	25.5	Feet
RS to Edge of Pavement	4.25	Feet	Facility Type	2U	
RS to Edge Line	1.83	Feet	Passing Allowed	No	
Edge Line to Edge of Pavement	6.08	Feet	Near Side Posted Speed Limit	55	MPH
Cardinal Direction	W		Far Side Posted Speed Limit	55	MPH
Roadway Direction	SB		Segment Type	Curve	Treatment

SITE SKETCH

No gravel shoulder, rumbles on asphalt; near side asphalt shoulder= 4'-11"; far side asphalt shoulder= 4'-9"; EOC to EOC= 24'-2"

PERSONNEL AND EQUIPMENT			
Personnnel	Grant, Tim, Abhinav	Site Number	65
Trailor	TDC 00164		
Equipment	Wavetronix		

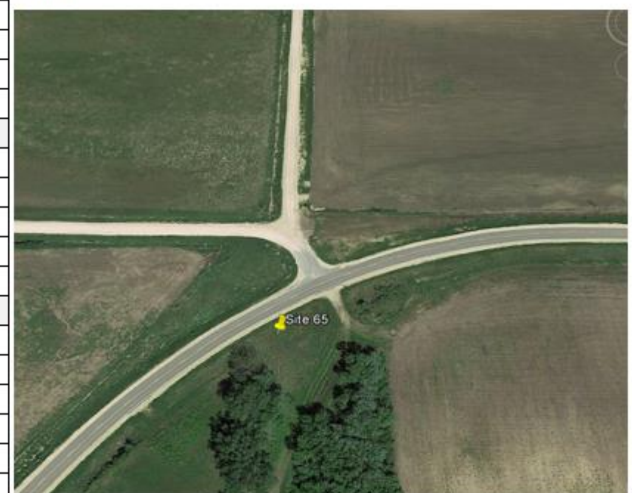
SETUP DETAILS	
Cooridinates	41°54'58.85"N, 90°51'34.65"W
Roadway	Y32
Nearest Town/City	Toronto
Start Time/Date	6/30/2016 13:40
Weather	Sunny
End Time/Date	7/6/2016 9:00
Weather	Sunny

MEASUREMENTS

Near Side			Centerline		
Type	Value	Unit	Type	Value	Unit
RS Width	NA	Inches	RS Width	NA	Inches
RS Length	NA	Inches	RS Length	NA	Inches
RS Spacing	NA	Inches	RS to RS Spacing	NA	Inches
Gravel Shoulder Width	6	Feet	Pair to Pair Spacing	NA	Inches
RS to Edge of Pavement	NA	Feet	**Trailer**		
RS to Edge Line	NA	Feet	Type	Value	Unit
Edge Line to Edge of Pavement	0.83	Feet	To Edge of Pavement	22.17	Feet
Cardinal Direction	E		To Edgeline	22.75	Feet
Roadway Direction	EB		To Rumble Strip	NA	Feet
Far Side			To Centerline	33.33	Feet
Type	Value	Unit	**Roadway**		
RS Width	NA	Inches	Type	Value	Unit
RS Length	NA	Inches	Edgeline to Edgeline	21	Feet
RS Spacing	NA	Inches	Edge of Pavement to Edge of Pavement	22.25	Feet
Gravel Shoulder Width	5	Feet	Rumble Strip to Rumble Strip	NA	Feet
RS to Edge of Pavement	NA	Feet	Facility Type	2U	
RS to Edge Line	NA	Feet	Passing Allowed	Near	
Edge Line to Edge of Pavement	0.83	Feet	Near Side Posted Speed Limit	55	MPH
Cardinal Direction	W		Far Side Posted Speed Limit	55	MPH
Roadway Direction	WB		Segment Type	Curve	Control

SITE SKETCH

Control



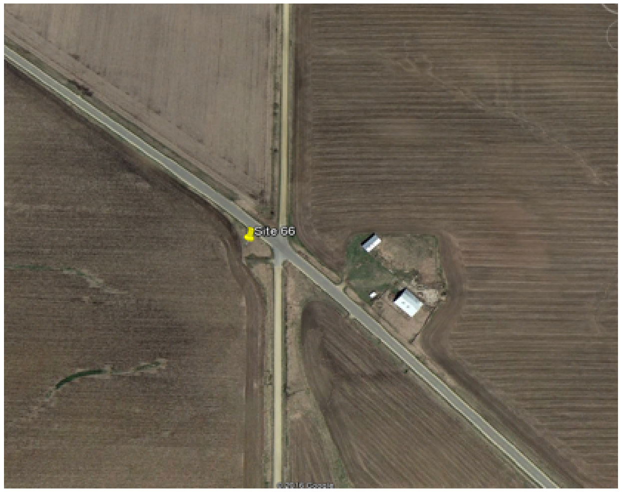
PERSONNEL AND EQUIPMENT			
Personnnel	Grant, Tim, Abhinav	Site Number	66
Trailor	TDC 00162		
Equipment	Wavetronix		

SETUP DETAILS	
Cooridinates	41°53'37.58"N, 90°51'35.91"W
Roadway	Y32
Nearest Town/City	Toronto
Start Time/Date	6/30/2016 11:50
Weather	Overcast
End Time/Date	7/6/2016 10:00
Weather	Overcast

MEASUREMENTS

Near Side			Centerline		
Type	Value	Unit	Type	Value	Unit
RS Width	8	Inches	RS Width	NA	Inches
RS Length	5	Inches	RS Length	NA	Inches
RS Spacing	13	Inches	RS to RS Spacing	NA	Inches
Gravel Shoulder Width	4	Feet	Pair to Pair Spacing	NA	Inches
RS to Edge of Pavement	3.17	Feet	**Trailer**		
RS to Edge Line	0	inches	Type	Value	Unit
Edge Line to Edge of Pavement	3.17	Feet	To Edge of Pavement	18.83	Feet
Cardinal Direction	SE		To Edgeline	22.08	Feet
Roadway Direction	SB		To Rumble Strip	22.08	Feet
Far Side			To Centerline	33	Feet
Type	Value	Unit	**Roadway**		
RS Width	7	Inches	Type	Value	Unit
RS Length	5	Inches	Edgeline to Edgeline	21.92	Feet
RS Spacing	13	Inches	Edge of Pavement to Edge of Pavement	28.08	Feet
Gravel Shoulder Width	4	Feet	Rumble Strip to Rumble Strip	21.83	Feet
RS to Edge of Pavement	3.08	Feet	Facility Type	2U	
RS to Edge Line	0.08	inches	Passing Allowed	Both	
Edge Line to Edge of Pavement	3	Feet	Near Side Posted Speed Limit	55	MPH
Cardinal Direction	NW		Far Side Posted Speed Limit	55	MPH
Roadway Direction	NB		Segment Type	Curve	Treatment

SITE SKETCH



APPENDIX B. RUMBLE STRIP SURVEY

Institute for Transportation (InTrans)
Rumble Strip Survey

This survey is being conducted to obtain feedback from Iowa road users about **centerline and shoulder rumble strips** on two-lane highways. Rumble strips are milled/grooved patterns in the pavement that create an audible (i.e., noise) and tactile (i.e., vibrations) warning to alert drivers when they are leaving their travel lane. **Please circle your best answer for each question.**

1. Are you familiar with rumble strips?
1 = Yes 2 = No

2. Have you driven on a two-lane highway where rumble strips were installed on the centerline of the road?
1 = Yes 2 = No 3 = Not sure

3. Have you driven on a two-lane highway where rumble strips were installed on the shoulder (outside edge) of the road?
1 = Yes 2 = No 3 = Not sure

4. Do rumble strips have an impact on how fast you drive on two-lane highways?
1 = Yes 2 = No

5. Have you ever driven over rumble strips?
1 = Yes 2 = No

If Yes, what were the reason(s)? ***(Circle all that apply.)***
1 = Unintentional contact during normal driving
2 = Contact while passing another vehicle
3 = Temporarily distracted
4 = Tired or fatigued
5 = Avoiding an object in the roadway
6 = Adverse weather conditions (e.g., rain, snow, fog)
7 = Nighttime conditions
8 = Other: ______________________________

6. Do you feel rumble strips provide sufficient feedback (i.e., noise and vibration) to alert drivers?
1 = Yes 2 = No 3 = Not sure

7. Do centerline rumble strips have an impact on how frequently you pass slower moving vehicles on two-lane highways?
1 = Yes 2 = No

8. Do you live on a two-lane highway where rumble strips have been installed near your house?
1 = Yes 2 = No

9. Do you feel rumble strips create any noise issues for nearby residents?
1 = Yes 2 = No 3 = Not sure

10. Do you ever bike along two-lane highways where rumble strips have been installed?
1 = Yes 2 = No

11. Do you feel rumble strips create any problems for bicyclists?
1 = Yes 2 = No 3 = Not sure

12. Do you ever walk or jog along two-lane highways where rumble strips have been installed?
1 = Yes 2 = No

13. Do you feel rumble strips create any problems for pedestrians or joggers?
1 = Yes 2 = No 3 = Not sure

14. On a scale from 1 (not effective) to 5 (very effective), how effective do you feel rumble strips are at alerting drivers under the following driving conditions:

	Not Effective				Very Effective
Daytime	1	2	3	4	5
Nighttime	1	2	3	4	5
Clear weather	1	2	3	4	5
Rain	1	2	3	4	5
Snow	1	2	3	4	5

15. Do you support the continued installation of rumble strips on two-lane highways throughout Iowa?
1 = Yes 2 = No

16. What is your gender?
1 = Male 2 = Female

17. What is your age?
1 = under 25
2 = 25-34
3 = 35-44
4 = 45-54
5 = 55-64
6 = 65 or above

18. What is your home zip code? ________________

19. Which type of personal automobile do you typically drive?
1 = Passenger car
2 = Sport utility vehicle (SUV)
3 = Pickup truck
4 = Van or minivan
5 = Motorcycle
6 = Commercial vehicle (large truck)
7 = Other:
____

Thank you for your assistance!

APPENDIX C. RUMBLE STRIP SURVEY RESPONSE SUMMARIES

Q1. Are you familiar with rumble strips?				
Q1	**Frequency**	**Percent**	**Cumulative Frequency**	**Cumulative Percent**
Yes 1	1401	94.85	1401	94.85
No 2	74	5.01	1475	99.86
Missing 9	2	0.14	1477	100.00

Q2. Have you driven on a two-lane highway where rumble strips were installed on the centerline of the road?				
Q2	**Frequency**	**Percent**	**Cumulative Frequency**	**Cumulative Percent**
Yes 1	1044	70.68	1044	70.68
No 2	246	16.66	1290	87.34
Not Sure 3	177	11.98	1467	99.32
Missing 9	10	0.68	1477	100.00

Q3. Have you driven on a two-lane highway where rumble strips were installed on the shoulder (outside edge) of the road?				
Q3	**Frequency**	**Percent**	**Cumulative Frequency**	**Cumulative Percent**
Yes 1	1298	87.88	1298	87.88
No 2	70	4.74	1368	92.62
Not Sure 3	99	6.70	1467	99.32
Missing 9	10	0.68	1477	100.00

Q4. Do rumble strips have an impact on how fast you drive on two-lane highways?				
Q4	**Frequency**	**Percent**	**Cumulative Frequency**	**Cumulative Percent**
Yes 1	520	35.21	520	35.21
No 2	939	63.57	1459	98.78
Missing 9	18	1.22	1477	100.00

Q5. Have you ever driven over rumble strips?				
Q5	**Frequency**	**Percent**	**Cumulative Frequency**	**Cumulative Percent**
Yes 1	1341	90.79	1341	90.79
No 2	135	9.14	1476	99.93
Missing 9	1	0.07	1477	100.00

Q5_1. Reason: Unintentional contact during normal driving				
Q5_1	**Frequency**	**Percent**	**Cumulative Frequency**	**Cumulative Percent**
Yes (Circled) 1	805	54.50	805	54.50
No (Not circled) 2	502	33.99	1307	88.49
Not Applicable (Q5 = No) or Missing 9	170	11.51	1477	100.00

Q5_2. Reason: Contact while passing another vehicle				
Q5_2	**Frequency**	**Percent**	**Cumulative Frequency**	**Cumulative Percent**
Yes (Circled) 1	419	28.37	419	28.37
No (Not circled) 2	888	60.12	1307	88.49
Not Applicable (Q5 = No) or Missing 9	170	11.51	1477	100.00

Q5_3. Reason: Temporarily distracted				
Q5_3	Frequency	Percent	Cumulative Frequency	Cumulative Percent
Yes (Circled) 1	405	27.42	405	27.42
No (Not circled) 2	902	61.07	1307	88.49
Not Applicable (Q5 = No) or Missing 9	170	11.51	1477	100.00

Q5_4. Reason: Tired or fatigued				
Q5_4	Frequency	Percent	Cumulative Frequency	Cumulative Percent
Yes (Circled) 1	286	19.36	286	19.36
No (Not circled) 2	1021	69.13	1307	88.49
Not Applicable (Q5 = No) or Missing 9	170	11.51	1477	100.00

Q5_5. Reason: Avoiding an object in the roadway				
Q5_5	Frequency	Percent	Cumulative Frequency	Cumulative Percent
Yes (Circled) 1	601	40.69	601	40.69
No (Not circled) 2	706	47.80	1307	88.49
Not Applicable (Q5 = No) or Missing 9	170	11.51	1477	100.00

Q5_6. Reason: Adverse weather conditions (e.g., rain, snow, fog)				
Q5_6	Frequency	Percent	Cumulative Frequency	Cumulative Percent
Yes (Circled) 1	382	25.86	382	25.86
No (Not circled) 2	925	62.63	1307	88.49
Not Applicable (Q5 = No) or Missing 9	170	11.51	1477	100.00

Q5_7. Reason: Nighttime conditions				
Q5_7	Frequency	Percent	Cumulative Frequency	Cumulative Percent
Yes (Circled) 1	226	15.30	226	15.30
No (Not circled) 2	1081	73.19	1307	88.49
Not Applicable (Q5 = No) or Missing 9	170	11.51	1477	100.00

Q5_8. Reason: Other reasons				
Q5_8	Frequency	Percent	Cumulative Frequency	Cumulative Percent
Yes (Circled) 1	16	1.08	16	1.08
No (Not circled) 2	1291	87.41	1307	88.49
Not Applicable (Q5 = No) or Missing 9	170	11.51	1477	100.00

Q5other Explanation				
Q5other	Frequency	Percent	Cumulative Frequency	Cumulative Percent
Pulled over by patrol car, car trouble, flat tire 1	14	0.95	14	0.95
No other reason, Not Applicable (Q5 = No), or Missing 9	1463	99.05	1477	100.00

Q6. Do you feel rumble strips provide sufficient feedback (i.e., noise and vibration) to alert drivers?				
Q6	Frequency	Percent	Cumulative Frequency	Cumulative Percent
Yes 1	1360	92.08	1360	92.08
No 2	40	2.71	1400	94.79
Not Sure 3	73	4.94	1473	99.73
Missing 9	4	0.27	1477	100.00

Q7. Do centerline rumble strips have an impact on how frequently you pass slower moving vehicles on two-lane highways?				
Q7	Frequency	Percent	Cumulative Frequency	Cumulative Percent
Yes 1	423	28.64	423	28.64
No 2	1002	67.84	1425	96.48
Missing 9	52	3.52	1477	100.00

Q8. Do you live on a two-lane highway where rumble strips have been installed near your house?				
Q8	Frequency	Percent	Cumulative Frequency	Cumulative Percent
Yes 1	171	11.58	171	11.58
No 2	1298	87.88	1469	99.46
Missing 9	8	0.54	1477	100.00

Q9. Do you feel rumble strips create any noise issues for nearby residents?				
Q9	Frequency	Percent	Cumulative Frequency	Cumulative Percent
Yes 1	146	9.88	146	9.88
No 2	735	49.76	881	59.65
Not Sure 3	591	40.01	1472	99.66
Missing 9	5	0.34	1477	100.00

Q10. Do you ever bike along two-lane highways where rumble strips have been installed?				
Q10	Frequency	Percent	Cumulative Frequency	Cumulative Percent
Yes 1	172	11.65	172	11.65
No 2	1302	88.15	1474	99.80
Missing 9	3	0.20	1477	100.00

Q11. Do you feel rumble strips create any problems for bicyclists?				
Q11	Frequency	Percent	Cumulative Frequency	Cumulative Percent
Yes 1	214	14.49	214	14.49
No 2	366	24.78	580	39.27
Not Sure 3	892	60.39	1472	99.66
Missing 9	5	0.34	1477	100.00

Q12. Do you ever walk or jog along two-lane highways where rumble strips have been installed?				
Q12	Frequency	Percent	Cumulative Frequency	Cumulative Percent
Yes 1	187	12.66	187	12.66
No 2	1285	87.00	1472	99.66
Missing 9	5	0.34	1477	100.00

Q13. Do you feel rumble strips create any problems for pedestrians or joggers?				
Q13	Frequency	Percent	Cumulative Frequency	Cumulative Percent
Yes 1	94	6.36	94	6.36
No 2	631	42.72	725	49.09
Not Sure 3	741	50.17	1466	99.26
Missing 9	11	0.74	1477	100.00

Q14Day. How effective do you feel rumble strips are at alerting drivers in Daytime?				
Q14Day	**Frequency**	**Percent**	**Cumulative Frequency**	**Cumulative Percent**
Not Effective 1	76	5.15	76	5.15
2	72	4.87	148	10.02
3	337	22.82	485	32.84
4	311	21.06	796	53.89
Very Effective 5	643	43.53	1439	97.43
Missing 9	38	2.57	1477	100.00

Q14Night. How effective do you feel rumble strips are at alerting drivers in Nighttime?				
Q14Night	**Frequency**	**Percent**	**Cumulative Frequency**	**Cumulative Percent**
Not Effective 1	29	1.96	29	1.96
2	26	1.76	55	3.72
3	131	8.87	186	12.59
4	305	20.65	491	33.24
Very Effective 5	949	64.25	1440	97.49
Missing 9	37	2.51	1477	100.00

Q14Clear. How effective do you feel rumble strips are at alerting drivers in Clear Weather?				
Q14Clear	**Frequency**	**Percent**	**Cumulative Frequency**	**Cumulative Percent**
Not Effective 1	76	5.15	76	5.15
2	95	6.43	171	11.58
3	317	21.46	488	33.04
4	287	19.43	775	52.47
Very Effective 5	641	43.40	1416	95.87
Missing 9	61	4.13	1477	100.00

Q14Rain. How effective do you feel rumble strips are at alerting drivers in Rain?				
Q14Rain	**Frequency**	**Percent**	**Cumulative Frequency**	**Cumulative Percent**
Not Effective 1	41	2.78	41	2.78
2	31	2.10	72	4.87
3	206	13.95	278	18.82
4	334	22.61	612	41.44
Very Effective 5	809	54.77	1421	96.21
Missing 9	56	3.79	1477	100.00

Q14Snow. How effective do you feel rumble strips are at alerting drivers in Snow?				
Q14Snow	**Frequency**	**Percent**	**Cumulative Frequency**	**Cumulative Percent**
Not Effective 1	99	6.70	99	6.70
2	109	7.38	208	14.08
3	289	19.57	497	33.65
4	235	15.91	732	49.56
Very Effective 5	688	46.58	1420	96.14
Missing 9	57	3.86	1477	100.00

Q15. Do you support the continued installation of rumble strips on two-lane highways throughout Iowa?				
Q15	**Frequency**	**Percent**	**Cumulative Frequency**	**Cumulative Percent**
Yes 1	1316	89.10	1316	89.10
No 2	123	8.33	1439	97.43
Missing 9	38	2.57	1477	100.00

Q16. What is your gender?				
Q16	**Frequency**	**Percent**	**Cumulative Frequency**	**Cumulative Percent**
Male 1	772	52.27	772	52.27
Female 2	694	46.99	1466	99.26
Missing 9	11	0.74	1477	100.00

Q17. What is your age?				
Q17	**Frequency**	**Percent**	**Cumulative Frequency**	**Cumulative Percent**
Under 25 1	374	25.32	374	25.32
25 – 34 2	325	22.00	699	47.33
35 – 44 3	284	19.23	983	66.55
45 – 54 4	236	15.98	1219	82.53
55 – 64 5	117	7.92	1336	90.45
65 or above 6	135	9.14	1471	99.59
Missing 9	6	0.41	1477	100.00

Q18. What is your home Zip Code?				
Zip Code	Frequency	Percent	Cumulative Frequency	Cumulative Percent
08861	1	0.07	1	0.07
10014	1	0.07	2	0.14
12345	1	0.07	3	0.20
15723	1	0.07	4	0.27
20024	1	0.07	5	0.34
24620	1	0.07	6	0.41
25766	1	0.07	7	0.47
27265	1	0.07	8	0.54
28213	1	0.07	9	0.61
29812	1	0.07	10	0.68
30349	1	0.07	11	0.74
30635	1	0.07	12	0.81
34787	1	0.07	13	0.88
35810	1	0.07	14	0.95
38106	1	0.07	15	1.02
39038	1	0.07	16	1.08
40216	1	0.07	17	1.15
45320	1	0.07	18	1.22
46383	1	0.07	19	1.29
50007	1	0.07	20	1.35
50009	13	0.88	33	2.23
50010	29	1.96	62	4.20
50014	22	1.49	84	5.69
50021	20	1.35	104	7.04
50023	26	1.76	130	8.80
50025	1	0.07	131	8.87
50035	5	0.34	136	9.21
50036	8	0.54	144	9.75
50046	4	0.27	148	10.02

Q18. What is your home Zip Code?				
Zip Code	Frequency	Percent	Cumulative Frequency	Cumulative Percent
50047	2	0.14	150	10.16
50055	1	0.07	151	10.22
50056	1	0.07	152	10.29
50058	3	0.20	155	10.49
50063	1	0.07	156	10.56
50076	1	0.07	157	10.63
50109	3	0.20	160	10.83
50111	8	0.54	168	11.37
50120	1	0.07	169	11.44
50124	3	0.20	172	11.65
50125	1	0.07	173	11.71
50130	1	0.07	174	11.78
50131	16	1.08	190	12.86
50134	2	0.14	192	13.00
50154	1	0.07	193	13.07
50161	2	0.14	195	13.20
50162	1	0.07	196	13.27
50169	2	0.14	198	13.41
50201	5	0.34	203	13.74
50203	1	0.07	204	13.81
50208	2	0.14	206	13.95
50211	2	0.14	208	14.08
50212	3	0.20	211	14.29
50220	1	0.07	212	14.35
50226	1	0.07	213	14.42
50232	1	0.07	214	14.49
50236	1	0.07	215	14.56
50237	1	0.07	216	14.62
50248	3	0.20	219	14.83

Q18. What is your home Zip Code?				
Zip Code	Frequency	Percent	Cumulative Frequency	Cumulative Percent
50249	3	0.20	222	15.03
50250	2	0.14	224	15.17
50263	3	0.20	227	15.37
50265	21	1.42	248	16.79
50266	10	0.68	258	17.47
50273	1	0.07	259	17.54
50278	2	0.14	261	17.67
50301	1	0.07	262	17.74
50309	3	0.20	265	17.94
50310	14	0.95	279	18.89
50311	6	0.41	285	19.30
50312	5	0.34	290	19.63
50313	10	0.68	300	20.31
50314	6	0.41	306	20.72
50315	21	1.42	327	22.14
50316	12	0.81	339	22.95
50317	15	1.02	354	23.97
50320	8	0.54	362	24.51
50321	3	0.20	365	24.71
50322	22	1.49	387	26.20
50323	2	0.14	389	26.34
50324	2	0.14	391	26.47
50325	1	0.07	392	26.54
50327	8	0.54	400	27.08
50401	53	3.59	453	30.67
50421	2	0.14	455	30.81
50423	1	0.07	456	30.87
50425	1	0.07	457	30.94
50428	15	1.02	472	31.96

Q18. What is your home Zip Code?				
Zip Code	Frequency	Percent	Cumulative Frequency	Cumulative Percent
50432	1	0.07	473	32.02
50434	1	0.07	474	32.09
50439	1	0.07	475	32.16
50441	2	0.14	477	32.30
50448	1	0.07	478	32.36
50456	5	0.34	483	32.70
50458	3	0.20	486	32.90
50464	4	0.27	490	33.18
50468	1	0.07	491	33.24
50469	3	0.20	494	33.45
50471	2	0.14	496	33.58
50478	1	0.07	497	33.65
50484	2	0.14	499	33.78
50501	26	1.76	525	35.55
50524	2	0.14	527	35.68
50525	1	0.07	528	35.75
50530	1	0.07	529	35.82
50532	1	0.07	530	35.88
50533	2	0.14	532	36.02
50543	2	0.14	534	36.15
50548	2	0.14	536	36.29
50556	1	0.07	537	36.36
50557	2	0.14	539	36.49
50558	1	0.07	540	36.56
50560	1	0.07	541	36.63
50579	1	0.07	542	36.70
50583	1	0.07	543	36.76
50588	1	0.07	544	36.83
50595	3	0.20	547	37.03

Q18. What is your home Zip Code?				
Zip Code	**Frequency**	**Percent**	**Cumulative Frequency**	**Cumulative Percent**
50604	2	0.14	549	37.17
50613	39	2.64	588	39.81
50622	1	0.07	589	39.88
50624	1	0.07	590	39.95
50626	3	0.20	593	40.15
50629	2	0.14	595	40.28
50634	1	0.07	596	40.35
50638	1	0.07	597	40.42
50643	1	0.07	598	40.49
50644	4	0.27	602	40.76
50648	2	0.14	604	40.89
50651	6	0.41	610	41.30
50653	1	0.07	611	41.37
50655	1	0.07	612	41.44
50658	2	0.14	614	41.57
50660	4	0.27	618	41.84
50662	3	0.20	621	42.04
50665	2	0.14	623	42.18
50667	1	0.07	624	42.25
50668	2	0.14	626	42.38
50669	3	0.20	629	42.59
50674	3	0.20	632	42.79
50676	1	0.07	633	42.86
50701	33	2.23	666	45.09
50702	34	2.30	700	47.39
50703	33	2.23	733	49.63
50707	9	0.61	742	50.24
51401	11	0.74	753	50.98
51430	1	0.07	754	51.05

Q18. What is your home Zip Code?				
Zip Code	**Frequency**	**Percent**	**Cumulative Frequency**	**Cumulative Percent**
51436	1	0.07	755	51.12
51443	1	0.07	756	51.18
51453	1	0.07	757	51.25
51455	1	0.07	758	51.32
51458	1	0.07	759	51.39
51462	1	0.07	760	51.46
51501	54	3.66	814	55.11
51503	47	3.18	861	58.29
51510	4	0.27	865	58.56
51521	3	0.20	868	58.77
51526	2	0.14	870	58.90
51529	1	0.07	871	58.97
51530	1	0.07	872	59.04
51534	2	0.14	874	59.17
51542	3	0.20	877	59.38
51549	1	0.07	878	59.44
51559	1	0.07	879	59.51
51560	1	0.07	880	59.58
51565	1	0.07	881	59.65
51566	1	0.07	882	59.72
51575	2	0.14	884	59.85
51579	1	0.07	885	59.92
51639	1	0.07	886	59.99
52001	60	4.06	946	64.05
52002	26	1.76	972	65.81
52003	21	1.42	993	67.23
52006	1	0.07	994	67.30
52031	1	0.07	995	67.37
52032	2	0.14	997	67.50

Q18. What is your home Zip Code?				
Zip Code	**Frequency**	**Percent**	**Cumulative Frequency**	**Cumulative Percent**
52033	3	0.20	1000	67.70
52035	1	0.07	1001	67.77
52039	1	0.07	1002	67.84
52040	7	0.47	1009	68.31
52045	4	0.27	1013	68.58
52046	3	0.20	1016	68.79
52054	1	0.07	1017	68.86
52057	5	0.34	1022	69.19
52060	2	0.14	1024	69.33
52065	3	0.20	1027	69.53
52068	5	0.34	1032	69.87
52070	1	0.07	1033	69.94
52073	3	0.20	1036	70.14
52157	1	0.07	1037	70.21
52159	1	0.07	1038	70.28
52202	1	0.07	1039	70.35
52203	1	0.07	1040	70.41
52205	2	0.14	1042	70.55
52209	1	0.07	1043	70.62
52211	1	0.07	1044	70.68
52218	1	0.07	1045	70.75
52224	1	0.07	1046	70.82
52225	1	0.07	1047	70.89
52230	1	0.07	1048	70.95
52233	7	0.47	1055	71.43
52235	2	0.14	1057	71.56
52237	1	0.07	1058	71.63
52240	35	2.37	1093	74.00
52241	24	1.62	1117	75.63

Q18. What is your home Zip Code?				
Zip Code	Frequency	Percent	Cumulative Frequency	Cumulative Percent
52242	5	0.34	1122	75.96
52245	15	1.02	1137	76.98
52246	17	1.15	1154	78.13
52247	3	0.20	1157	78.33
52253	2	0.14	1159	78.47
52276	1	0.07	1160	78.54
52301	1	0.07	1161	78.61
52302	22	1.49	1183	80.09
52304	1	0.07	1184	80.16
52314	4	0.27	1188	80.43
52317	22	1.49	1210	81.92
52322	5	0.34	1215	82.26
52324	1	0.07	1216	82.33
52333	9	0.61	1225	82.94
52336	1	0.07	1226	83.01
52337	1	0.07	1227	83.07
52338	3	0.20	1230	83.28
52340	2	0.14	1232	83.41
52358	2	0.14	1234	83.55
52361	1	0.07	1235	83.62
52400	1	0.07	1236	83.68
52401	3	0.20	1239	83.89
52402	37	2.51	1276	86.39
52403	27	1.83	1303	88.22
52404	57	3.86	1360	92.08
52405	27	1.83	1387	93.91
52411	7	0.47	1394	94.38
52466	1	0.07	1395	94.45
52551	1	0.07	1396	94.52

Q18. What is your home Zip Code?				
Zip Code	**Frequency**	**Percent**	**Cumulative Frequency**	**Cumulative Percent**
52601	1	0.07	1397	94.58
52602	1	0.07	1398	94.65
52627	1	0.07	1399	94.72
52641	1	0.07	1400	94.79
52720	1	0.07	1401	94.85
52732	1	0.07	1402	94.92
52738	1	0.07	1403	94.99
52746	1	0.07	1404	95.06
52747	1	0.07	1405	95.13
52755	2	0.14	1407	95.26
52766	1	0.07	1408	95.33
52772	3	0.20	1411	95.53
52776	9	0.61	1420	96.14
52777	2	0.14	1422	96.28
52778	2	0.14	1424	96.41
52803	1	0.07	1425	96.48
52807	1	0.07	1426	96.55
53811	1	0.07	1427	96.61
55407	1	0.07	1428	96.68
56027	1	0.07	1429	96.75
60424	1	0.07	1430	96.82
60565	1	0.07	1431	96.89
64158	1	0.07	1432	96.95
65672	1	0.07	1433	97.02
67216	1	0.07	1434	97.09
68110	1	0.07	1435	97.16
68147	1	0.07	1436	97.22
71411	1	0.07	1437	97.29
74074	1	0.07	1438	97.36

Q18. What is your home Zip Code?				
Zip Code	**Frequency**	**Percent**	**Cumulative Frequency**	**Cumulative Percent**
80631	1	0.07	1439	97.43
89102	1	0.07	1440	97.49
98550	1	0.07	1441	97.56
99999	36	2.44	1477	100.00

Q19. Which type of personal automobile do you typically drive?				
Q19	**Frequency**	**Percent**	**Cumulative Frequency**	**Cumulative Percent**
Passenger car 1	777	52.61	777	52.61
Sport utility vehicle (SUV) 2	301	20.38	1078	72.99
Pickup truck 3	199	13.47	1277	86.46
Van or minivan 4	100	6.77	1377	93.23
Motorcycle 5	28	1.90	1405	95.13
Commercial vehicle (large truck) 6	46	3.11	1451	98.24
Other 7	11	0.74	1462	98.98
Missing 9	15	1.02	1477	100.00

Q19other. Other explanation				
Q19other	**Frequency**	**Percent**	**Cumulative Frequency**	**Cumulative Percent**
Non-driver, don’t drive 1	4	0.27	4	0.27
No other type of vehicle, Missing 9	1473	99.73	1477	100.00