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Installation guidance for centerline and edgeline rumble strips in narrow pavements

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Installation guidance for centerline and edgeline rumble strips in narrow pavements

by

Bijan Vafaei

A thesis submitted to the graduate faculty
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

Major: Civil Engineering (Transportation Engineering)

Program of Study Committee:
Peter Savolainen, Major Professor
Anuj Sharma
Jennifer Shane

Iowa State University

Ames, Iowa

2017

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DEDICATION

For you Mom,

For each and every second you stay awake for me.

You are the one who taught me the meaning of life.

I could never have done this without your faith, support, and constant encouragement.

For you Dad,

For each and every second you were the only friend of mine.

You taught me what it means to be a man.

I would not be who I am without you.

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NOMENCLATURE

AADT	Annual Average Daily Traffic
AASHTO	American Association of State Highway and Transportation Officials
ADT	Average Daily Traffic
CLRS	Centerline rumble strips
DADS	Dynamic Analysis and Design System
DBA	A-weighted decibels
DOT	Department of Transportation
EB	Empirical Bayes
EL	Edgeline
ELRS	Edgeline rumble strips
FHWA	Federal Highway Administration
FO	Fixed Object
GIMS	Geographic Information Management System
HSIP	Highway Safety Improvement Program
IID	Independently and Identically Distributed
MDOT	Michigan Department of Transportation
MV	Multi Vehicle
NCHRP	National Cooperative Highway Research Program
NCSDR	National Center on Sleep Disorders Research
NDS	Naturalistic Driving Study
NHTSA	National Highway Traffic Safety Administration

QA/QC	Quality Assurance/ Quality Control
RID	Roadway Information Database
ROR	Run-off-Road
RS	Rumble Strips
SFITD	Safety Feature Inventory Tracking Database
SHRP2	Second Strategic Highway Research Program
SPF	Safety Performance Function
SRS	Shoulder Rumble Strips
SV	Single Vehicle
WYDOT	Wyoming Department of Transportation
XCL	Cross Centerline

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ABSTRACT

Centerline Rumble strips (CLRS) and Shoulder rumble strips (SRS) and on two-lane rural highways are proven safety countermeasures which provide both an audible and tactile alert to motorists who are about to drift and depart away from their intended lane of travel along two-lane rural highways. Placement of both CLRS and SRS 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. Other 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. 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. Also 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 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 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 an approximately three months of field studies regarding the road user behaviors 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.

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.

CHAPTER 1: INTRODUCTION

1.1 Background

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.

Rumble strips are common countermeasures to reduce lane departure crashes which 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. 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. Research has demonstrated that the use of CLRS and SRS/ELRS, both individually and in combination, are effective low-cost countermeasures. 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 **Error! Reference source not found.** (Kay et al. 2015). Interestingly, these reductions were most pronounced when SRS were used in combination with CLRS, even though the study focused only on centerline-related crashes.

Table 1. Reductions in crashes by type of rumble strip installed (Kay et al. 2015)

Crash Type	Percent Reduction in Crashes	
	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.

1.2 Research Objectives

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. 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.

Consequently, 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. The guidance provides specific standards for the installation of rumble strips on narrow pavements based on traffic volume, roadway alignment, and shoulder type.

In support of this objective, the 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 throughout this study 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.

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.

1.3 Thesis Structure

This thesis is generally divided into six main chapters. This introductory chapter has established the background of the research problem of interest, in addition to describing the overall objectives of this study. The contents of subsequent chapters are briefly described below.

Chapter 2: Literature Review – This chapter presents a comprehensive state-of-the-art literature review of prior in-service evaluations of rumble strips on rural, two-lane highways. This review will assess impacts on safety, as well as supplementary concerns including traffic operations, noise, and concerns for non-motorized users. This review will also identify any guidelines, standards, and specifications used by state DOTs in determining circumstances where centerline or shoulder rumble strips are most effective, as well as any prioritization schemes that have been used to select candidate installation locations.

Chapter 3: Crash Analysis – This chapter 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. In addition, a detailed description of data collection and data preparation have been provided. The statistical methods used for the purposes of this analysis are also described in this chapter.

Chapter 4: Field Studies of Driver Behavior – This chapter 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: Public Survey – This chapter 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: Conclusions and Rumble Strips Installation Guidance – This chapter provides conclusions and recommendations to assist agencies in future rumble strip deployments based on the findings from this study.

CHAPTER 2: LITERATURE REVIEW

Lane departure and run-off-road (ROR) related crashes hold accountable 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 using data from multiple states. (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 significantly efficient 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 (Kay et al. 2015). This program involved the installation of milled centerline rumble strips on all non-freeway highways with a posted speed of 55 mph and above with a total paved width more

than 20 ft. Shoulder rumble strips were installed at locations where shoulder widths were 6 ft. and above. In total, more than 5,400 miles of highways were included in this rumble strip installation initiative. 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 exterior or interior 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 by Gate et al in 2015 for Michigan Department of Transportation (MDOT) that measured the increase in roadside noise associated with different centerline rumble strip depths and pavement surface types (Gates et al. 2015). The result of a series of field studies determined that the milled depth of the rumble strip was the most significant variable predicting 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 chip sealed 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.

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 Pennsylvania was conducted to investigate the safety concerns of bicyclists regarding the adverse impacts of shoulder rumble strips installation which might lead them to lose control while traversing over the shoulder rumble strips (Elfteriadou et. al., 2000). This study evaluated the ability of various rumble strips configurations to provide a ride for bicyclists that minimized the level of vibration, while still providing a sufficient amount of tactile and

audible alerts for the motorists (Elfteriadou et. al., 2000). First, existing rumble strips configurations were evaluated and ranked according to their potential of being bicycle-friendly.

Following this feedback solicitation, a series of field experiments were conducted to assess the effectiveness of various configurations. A simulation model was implemented to measure the vertical acceleration and pitch angular acceleration of the bicycle and the rider. In total, six configurations of rumble strips were simulated and 25 individuals volunteered to participate in a series of tests. Ultimately, 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.

A study in North Carolina evaluated the impact of SRS gap lengths and shoulder widths on bicyclists' ability to maneuver, speed, and comfort (O'Brien et al. 2014). Shoulder-to-lane and lane-to-shoulder maneuvers were examined through 18 unique scenarios. The results showed bicyclists to feel more comfortable while maneuvering through larger sized rumble strip gaps. While the current practice at that time was to separate series of SRS series with 12 ft. gaps, the authors recommended a 16 to 18 ft. gap to improve maneuverability while still alerting drivers who may leave their lane at a departure angle of three degrees or more.

Bicyclist comfort and safety may also be affected indirectly by vehicles crossing over CLRS during passing maneuvers. 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.

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 effects of rumble strips installation 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.

CHAPTER 3: CRASH ANALYSIS

To assess the Iowa-specific effects of rumble strip installations, a data set was constructed for the two-lane, two-way primary highway network. It was necessary to analyze primary highways as opposed to secondary roadways due to limitations in available data. To maximize the applicability of this research to the secondary roadway network, only the two-lane undivided portion of the primary roadway network was considered for this analysis. The two-way 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 indicates the screenshot of the tool used to create and reduce the Safety Feature Inventory Tracking Database.

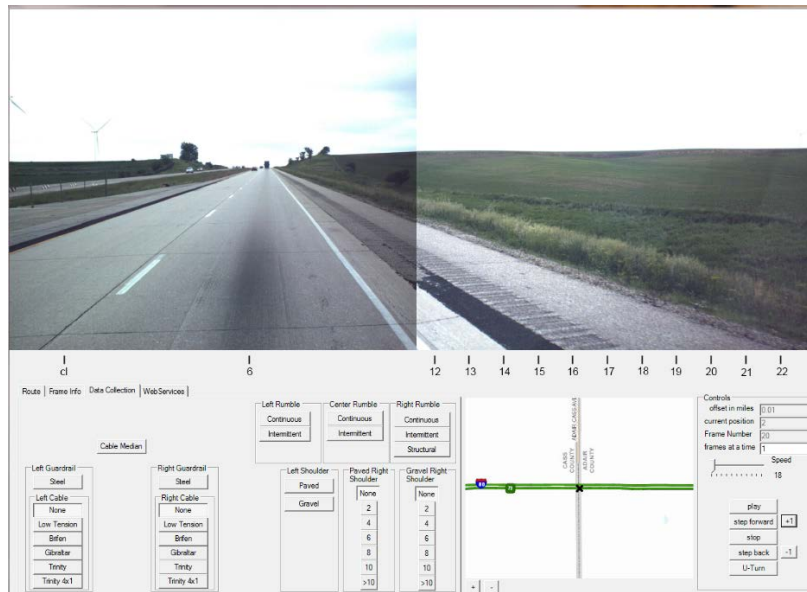


Figure 1. Safety Feature Inventory Tracking Database interface showing six rumble strip installation option

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. Incorrectness in dataset-coded as right continuous with left intermittent



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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.

Figure 4 shows two example of segments with continuous shoulder rumble strips with bicycle gaps which wrongly coded as intermittent on IA 141 and US 169.



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Figure 3. Actual intermittent rumble strip installation

Error! Reference source not found. 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 with bicycle safety gaps

Another issue with the coding of intermittent rumble strips is that they are mistakenly identified where gaps in the rumble strip 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. **Error! Reference source not found.** (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.



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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 mitigate data quality issues regarding rumble strip installation locations, data was obtained from the Iowa DOT Highway Safety Improvement Program (HSIP) project list (shown in Figure 8) and the GIMS Direct Lane file to minimize gaps in rumble strip information resulting from the biennial nature of the SFITD data collection process.

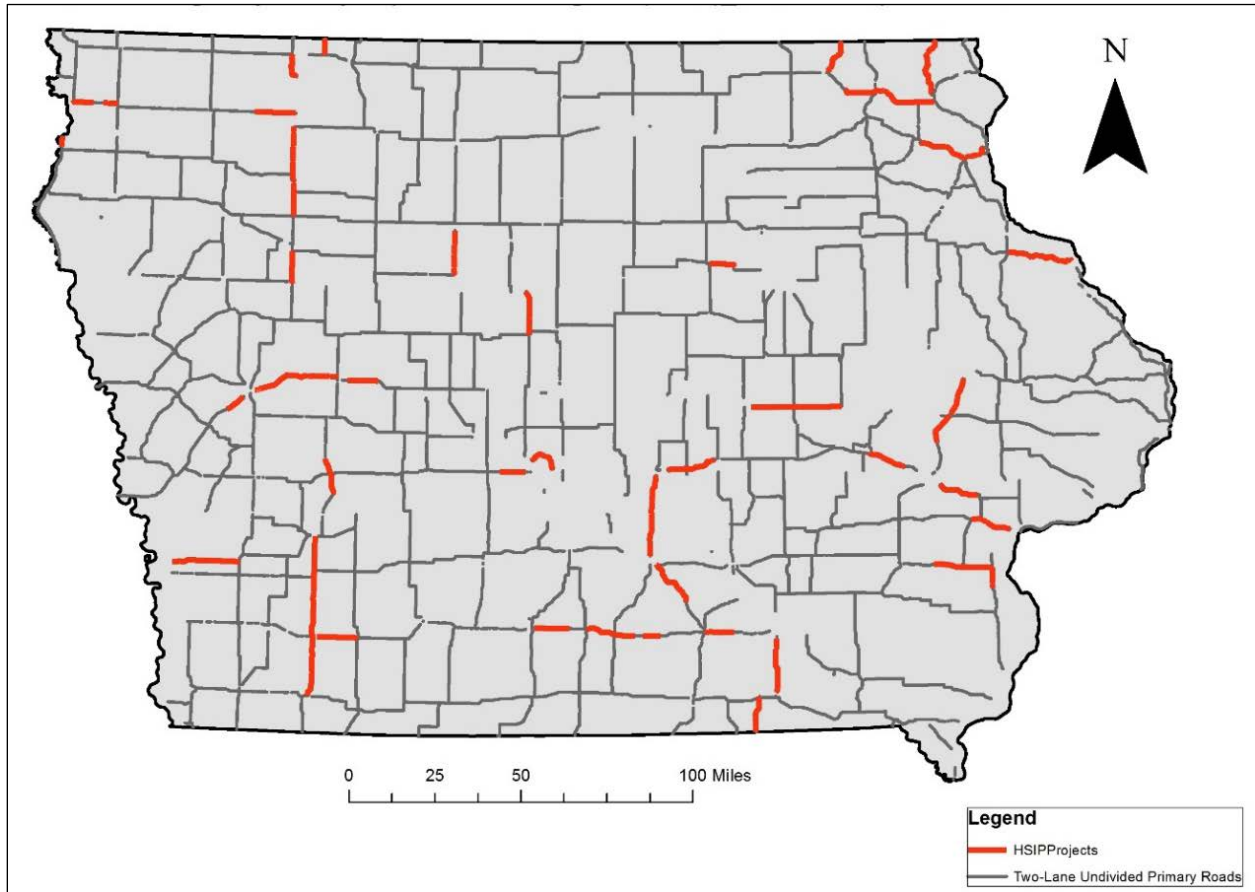


Figure 8. Rumble strip installation locations from the Highway Safety Improvement Program (HSIP)

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.

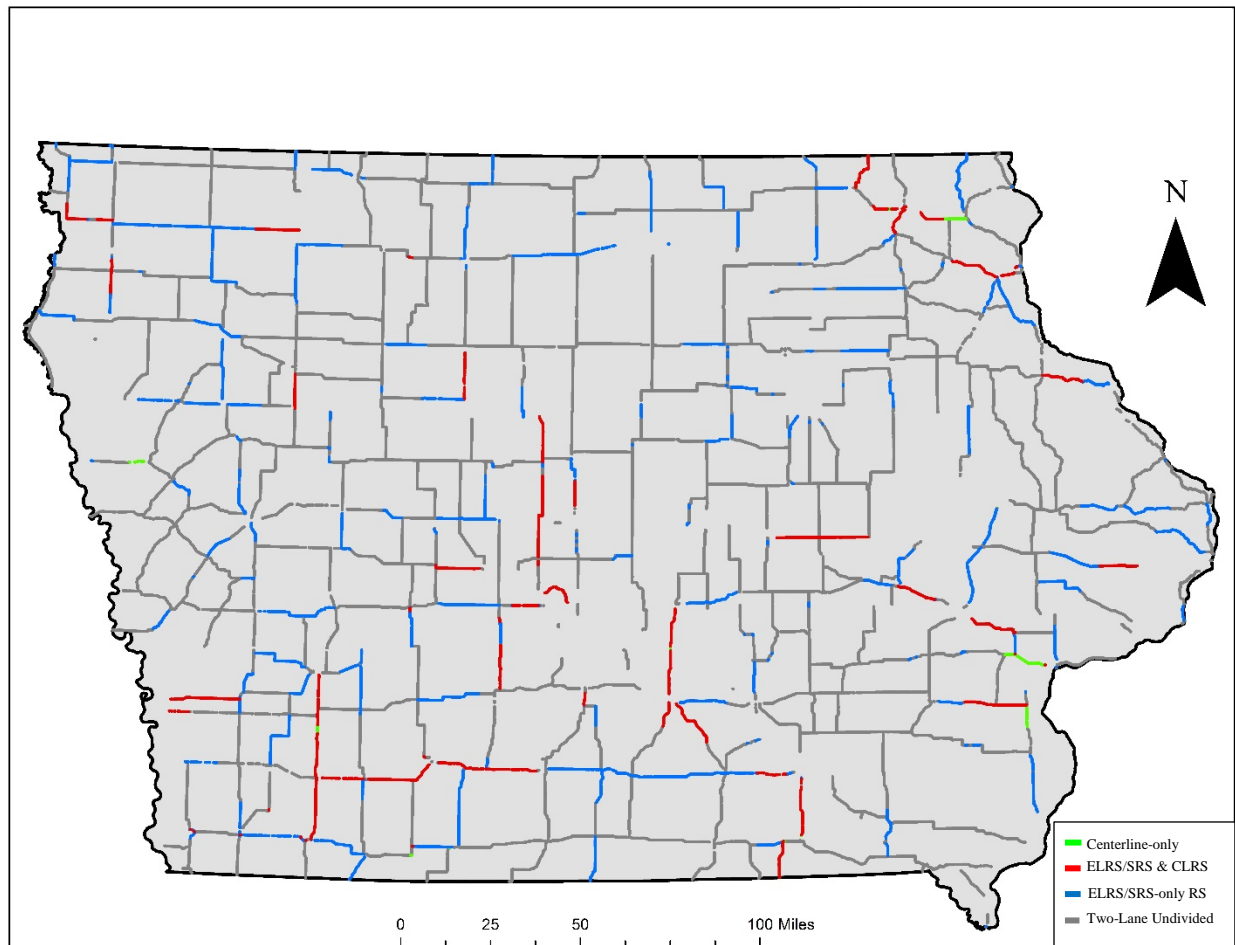


Figure 9. Iowa two-lane undivided primary roadway rumble strip installation locations

Using the completed rumble strip installation database, the GIMS roadway segments were split into analysis segments to ensure that only one type of rumble strip treatment (shoulder, center, both, or none) was present on a given segment. The GIMS database was 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. Aggregate level statewide crash data shows higher concentration of crashes nearer to urban and suburban areas of the state.

Table 3 shows descriptive statistics for 10,162 crashes occurring on the two-lane, undivided, primary highway network during the analysis period. A subset of crashes was identified as “target crashes,” i.e., crash types that would potentially be affected under the circumstances of rumble strips’ presence. This subset was then split into two types of target crashes, edgeline crashes and centerline crashes, each of which includes multiple subcategories, which are documented in Table 3. The target crash types are listed below:

- Single-vehicle run-off-road crashes
- Single-vehicle fixed object crashes
- Multiple-vehicle head-on crashes
- Multiple-vehicle cross centerline crashes
- Multiple-vehicle side-swipe crashes (same direction or opposite direction)

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

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.

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 ultimately 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 shown in Figure 10.

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 10 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.

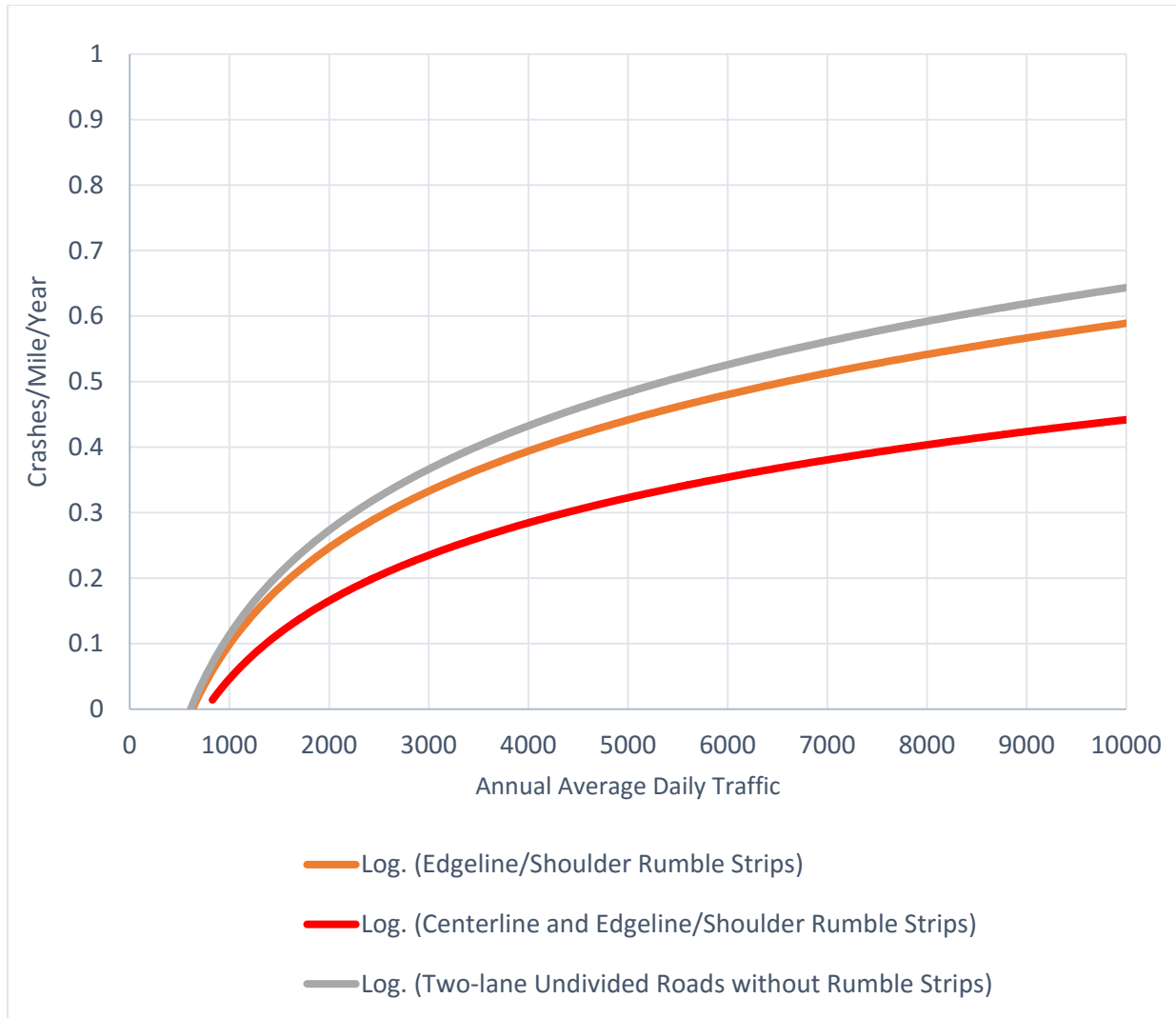


Figure 10. Best fit lines, traffic volume versus crashes, by rumble strip installation type

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	17,700	2,428.22	1,468.24	27,896
Truck Percentage	2	45	15	6	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 of time is given by the following equation:

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

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). The negative binomial model is preferred over the Poisson model since 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 expected 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 expected 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 development – rumble strips by location

Parameter	Estimate	Std. Error	z value	Pr(> z)	Reduction
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	23.3%
Edgeline/shoulder rumble strips	-0.108	0.056	-1.944	0.0519	10.2%
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 development – edgeline target crashes

Parameter	Estimate	Std. Error	z value	Pr(> z)	Reduction
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	16.1%
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 development – centerline target crashes

Parameter	Estimate	Std. Error	z value	Pr(> z)	Reduction
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	33.2%
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

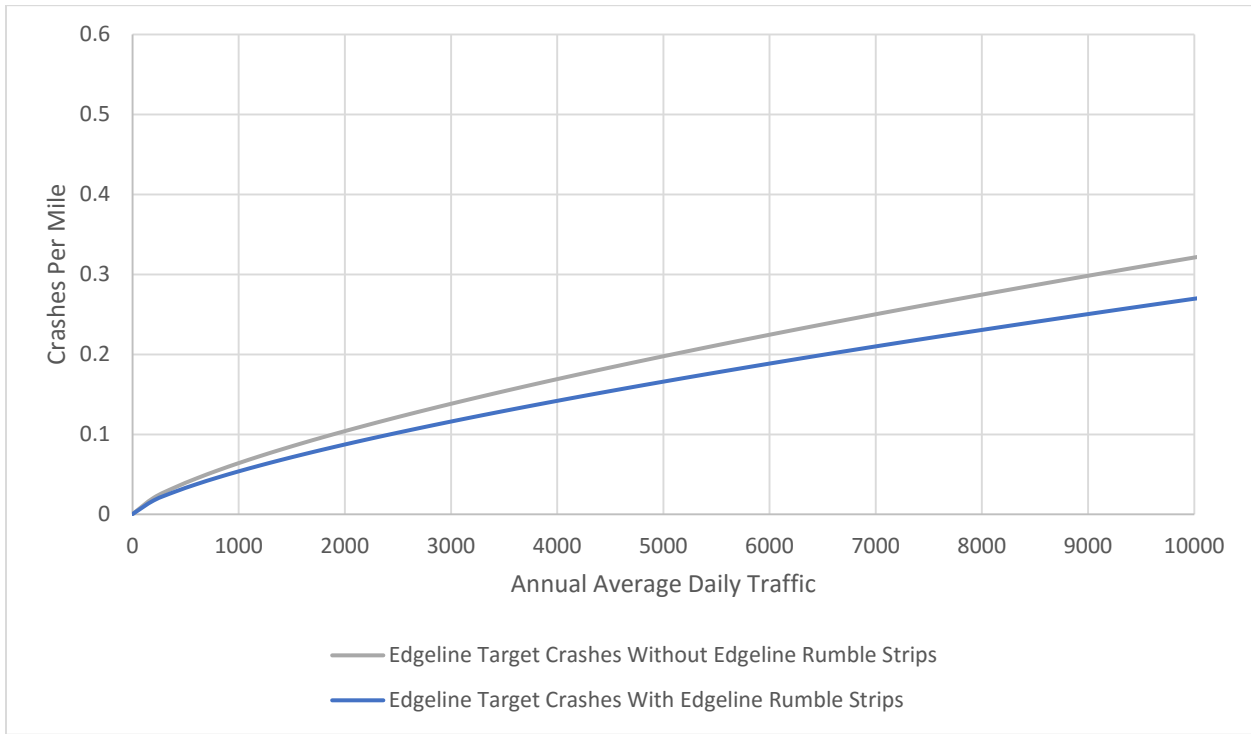


Figure 12. Graphical representation of SPF for edgeline crashes

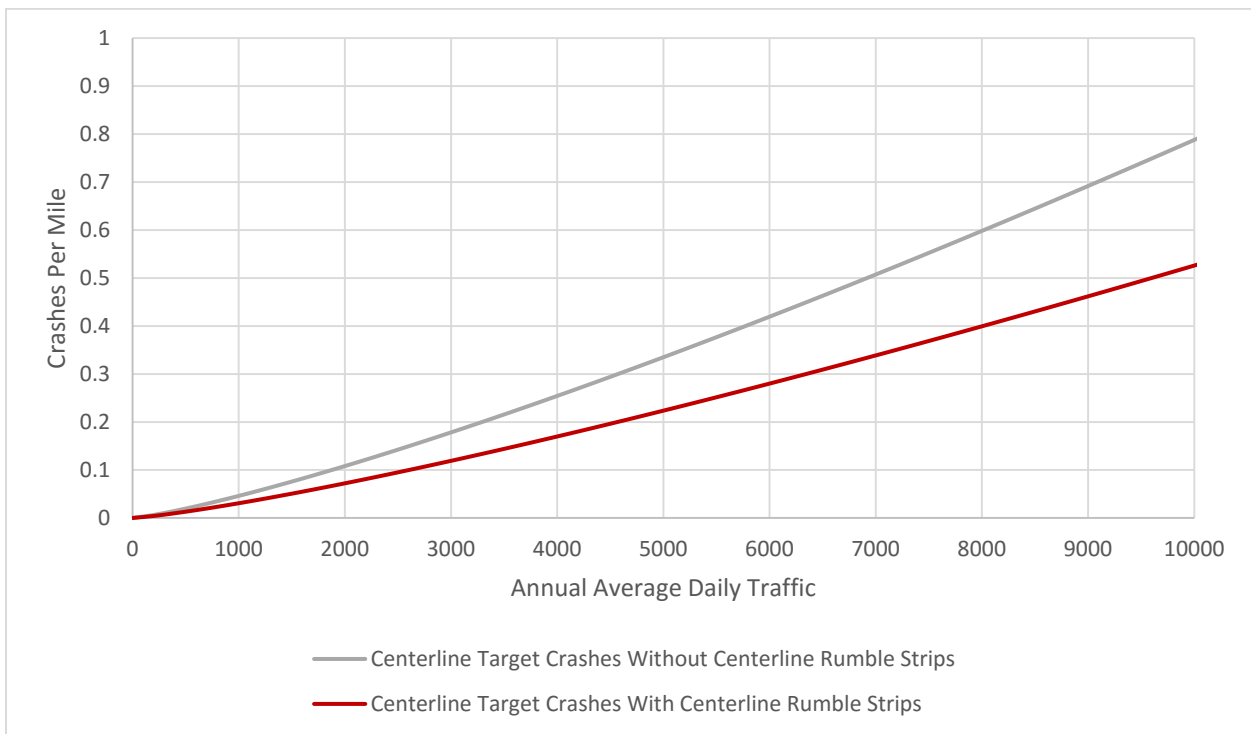


Figure 13. Graphical representation of SPF for centerline crashes

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.

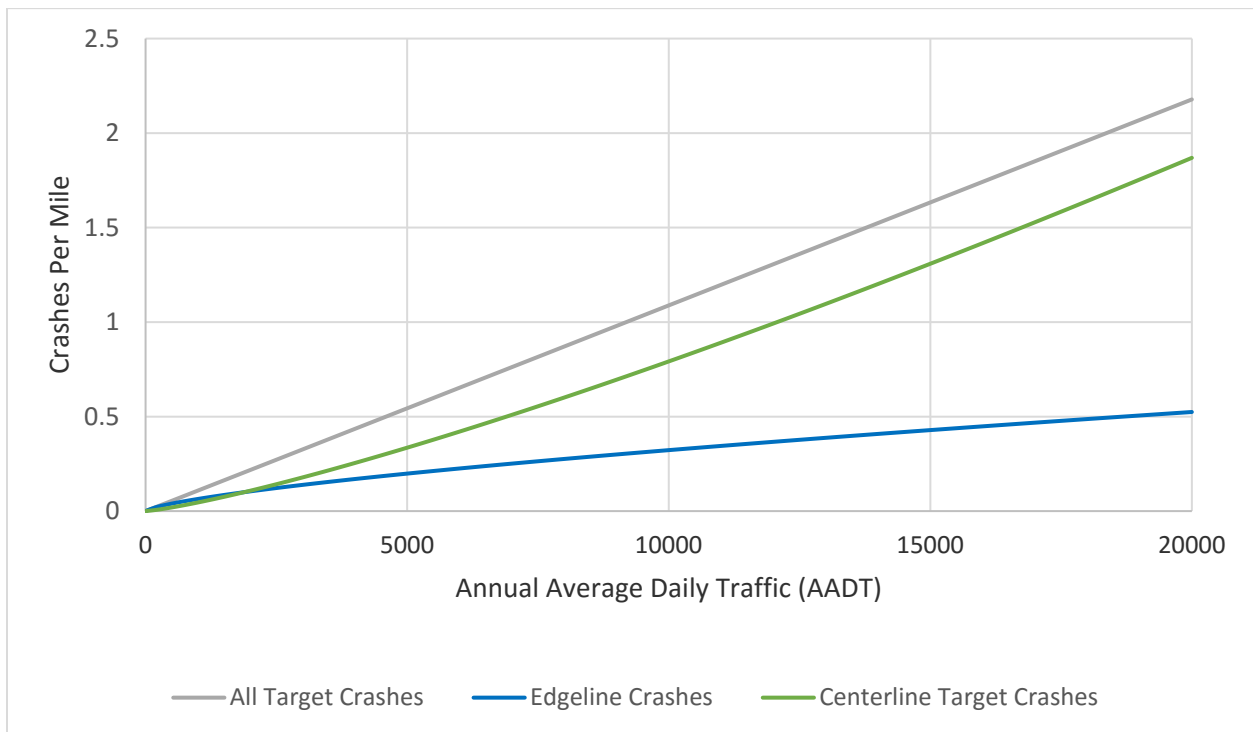


Figure 14. Target crashes by type and AADT

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) were considered separately, centerline-only rumble strips were found to be significantly associated with a reduction in expected centerline-related crashes while being associated with a negligible impact on edge crashes, and vice-versa for edge/shoulder rumble strips. The edgeline and shoulder rumble strip installations were found to be associated with lower crash frequencies. 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).

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 as the reduction percentages are documented in Table 5, Table 6, and Table 7. While the SPFs estimated in this study were specifically based 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 (Figure 15 top map is the statewide paved secondary roadway) 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, from 2011 to 2015, are shown in Table 8. More detailed information regarding the number of crashes occurring on the secondary roadway network from 2011 to 2015 is shown in Table 9.

Table 8. Secondary network descriptive statistics

	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	31900	1006.95	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	1,272.2
Total target crashes per year	0.06	0	3.8	0.15	2,825
Number of Observations					43,504

Table 9. 2011-2015 Crashes on secondary network descriptive statistics

Crash Type	Total	Severity				PDO
		K	A	B	C	
Total Crashes	32,915	474	1,592	4,075	4,818	21,956
Total Target	14,127	312	1,003	2,531	2,817	7,464
Edge Line Target	7,766	144	558	1,470	1,624	3,970
SV, ROR-Right, FO	3,955	82	307	758	826	1,982
SV, ROR-Right, No FO	1,834	42	128	390	438	836
SV, ROR-Straight/Right, FO	1,946	50	122	359	393	1,022
SV, ROR-Straight/Right, No FO	839	13	60	135	210	421
SV, No ROR, No XCL, FO	678	10	58	139	149	322
Centerline Target	6,361	168	445	1,061	1,193	3,494
SV, ROR-Left, FO	5	0	1	0	3	1
SV, ROR-Left, No FO	128	1	9	28	29	61
SV, ROR-Straight/Left, FO	2	0	0	0	1	1
SV, ROR-Straight/Left, No FO	812	25	81	168	165	373
SV, XCL, FO	334	8	23	82	76	145
SV, XCL, No FO	1,171	9	56	155	182	769
MV, Head-on	537	46	84	119	121	167
MV, Sideswipe-same	1,181	5	37	85	124	930
MV, Sideswipe-opposite	705	21	37	113	100	434

SV = Single-vehicle, MV = Multi-vehicle, ROR = Run-off-road, FO = Fixed Object, XCL = Cross Centerline

On average, roadway segments on the secondary network serve much lower traffic volumes than those on the primary network as are shown in Figure 15. 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 10.

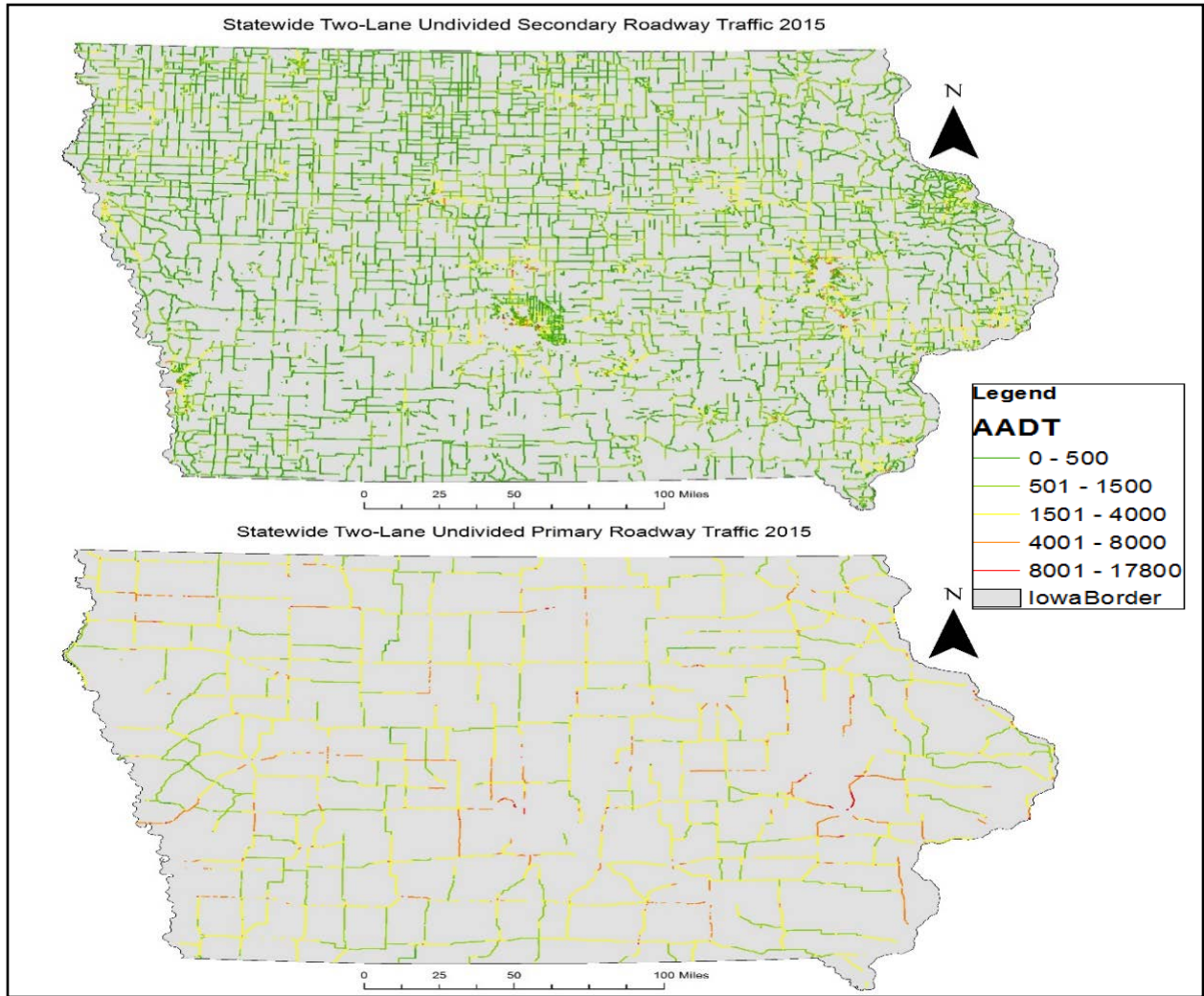


Figure 15. 2015 Traffic comparison on two-lane undivided primary (bottom) and secondary (top) roadway

Table 10. Calibration factors for the secondary network

SPF	Total Observed Crashes (per year)	Total Predicted Crashes (pear year)	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 11 and Table 12. 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 11. Projected crash frequency per year

Crash Type	Expected Crashes Per Year		
	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 12. Projected crash rate per mile per year

Crash Type	Expected Crash Rate Per Mile Per Year		
	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 16, Figure 17, and Figure 18 display the 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.

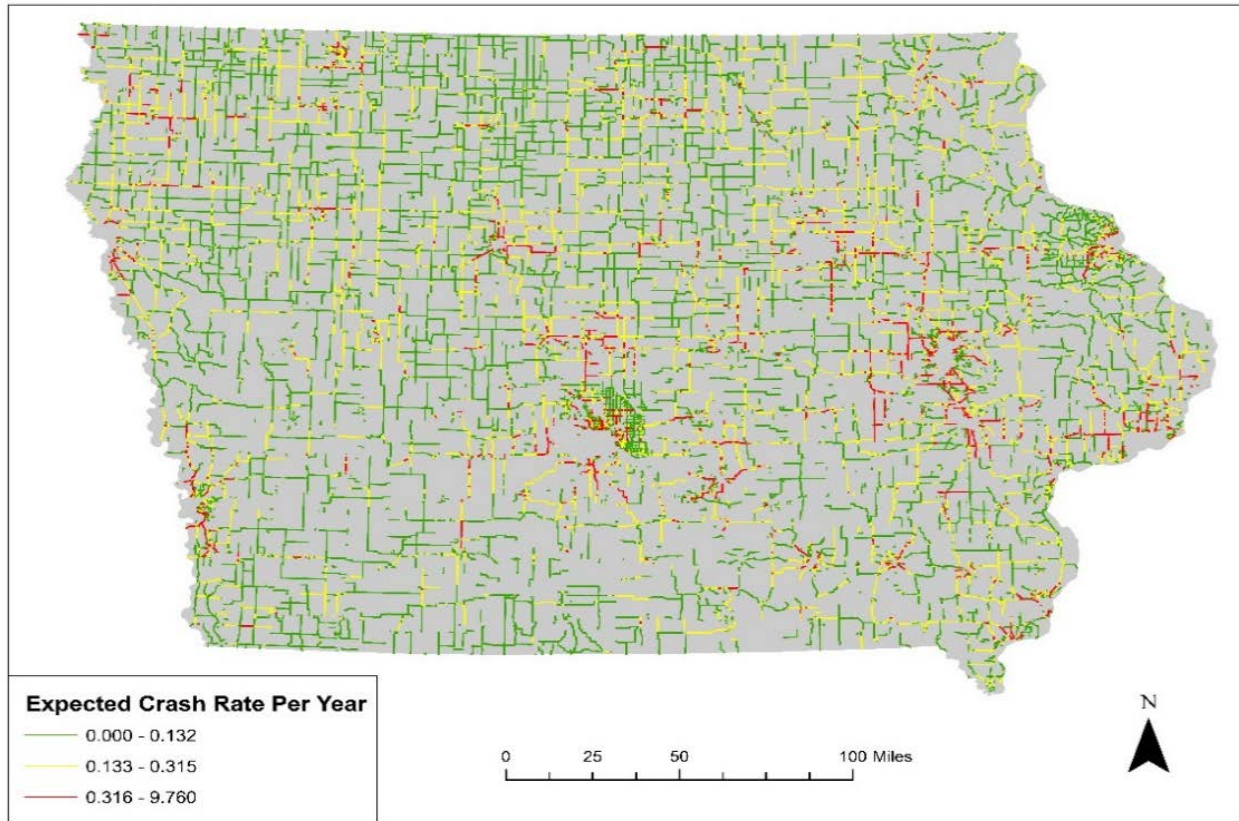


Figure 16. Expected centerline- and edgeline-related crashes per mile per year

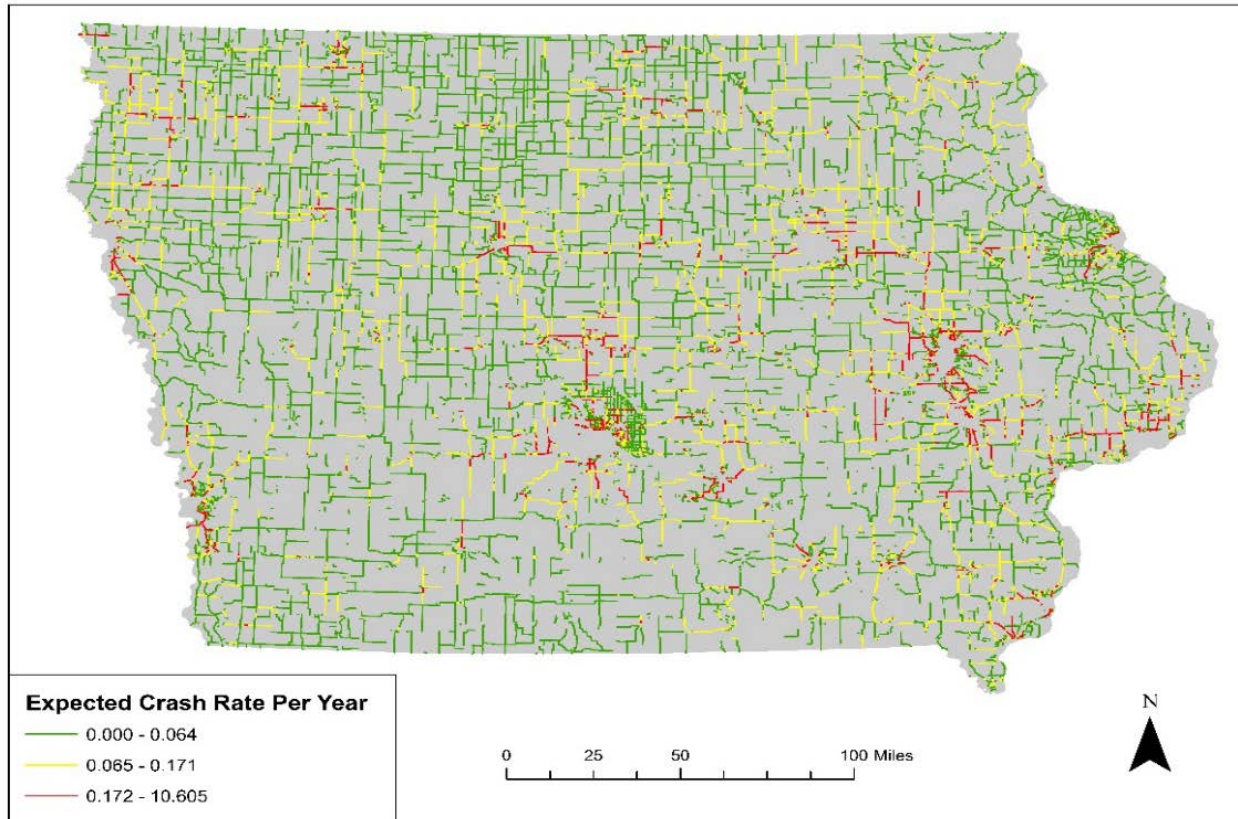


Figure 17. Expected centerline-related crashes per mile per year

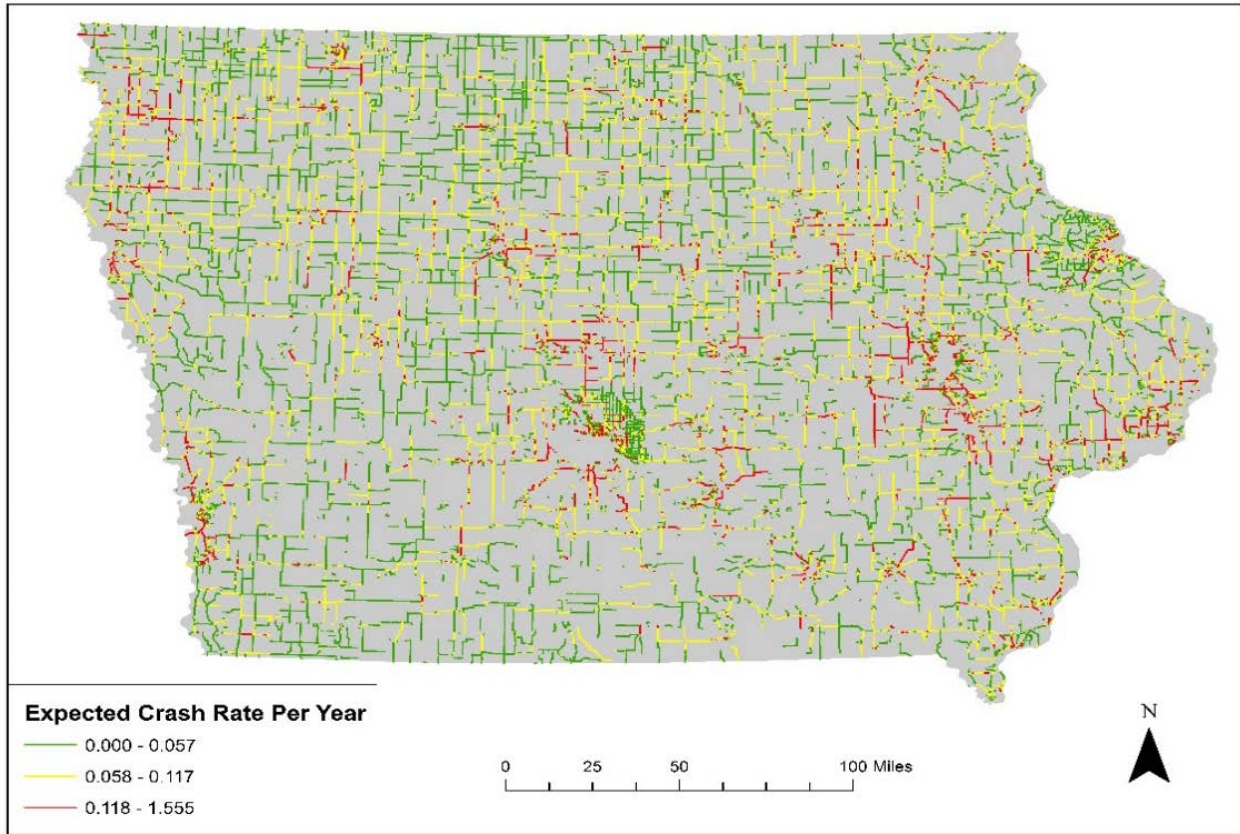


Figure 18. Expected edgeline-related crashes per mile per year

County road agencies may wish to look at the expected crash frequency in addition to the crash rate. To this end, Figure 19, Figure 20, and Figure 21 display the expected crash frequencies of the secondary road segments. Ultimately, these maps provide information regarding the locations where rumble strips could potentially have the largest impact.

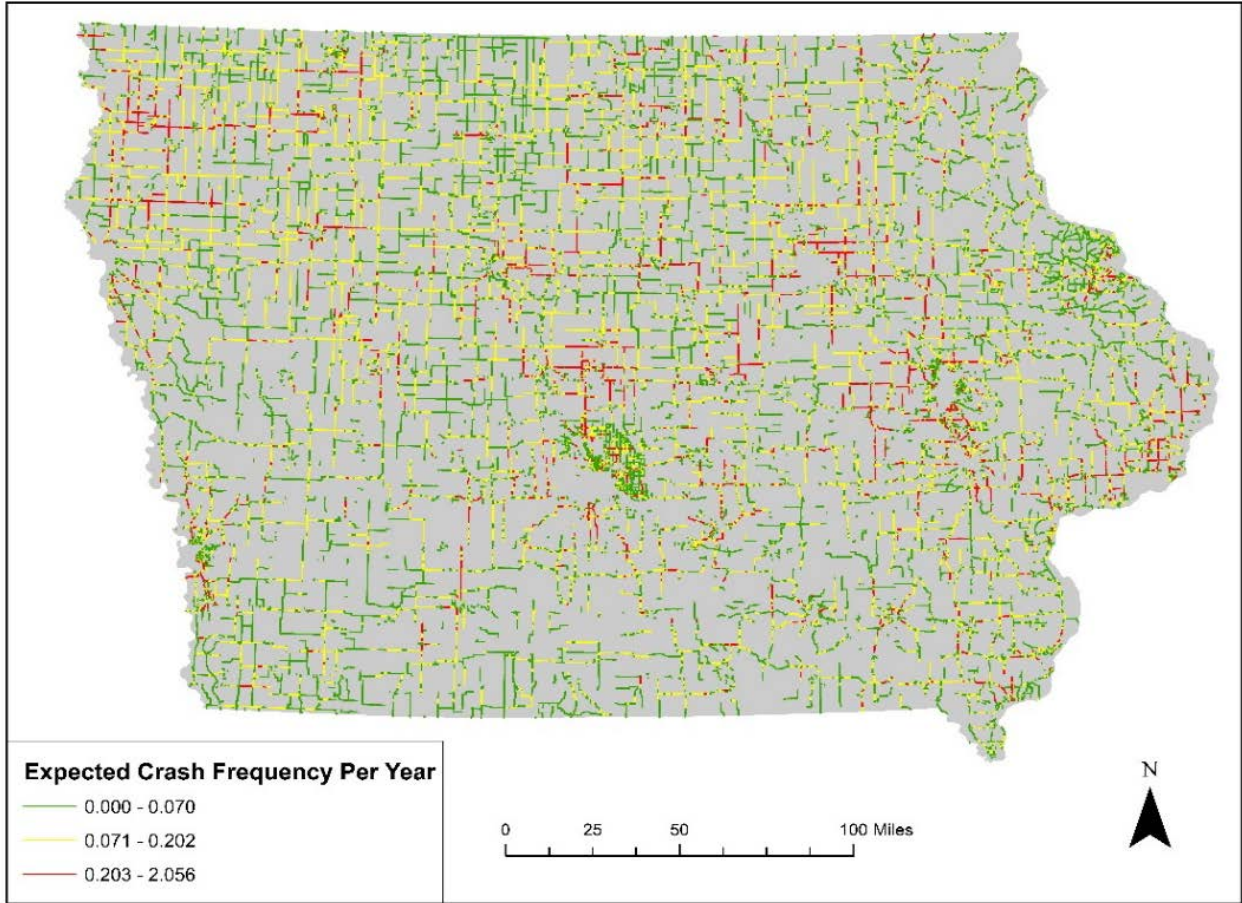


Figure 19. Expected edgeline- and centerline-related crashes per year

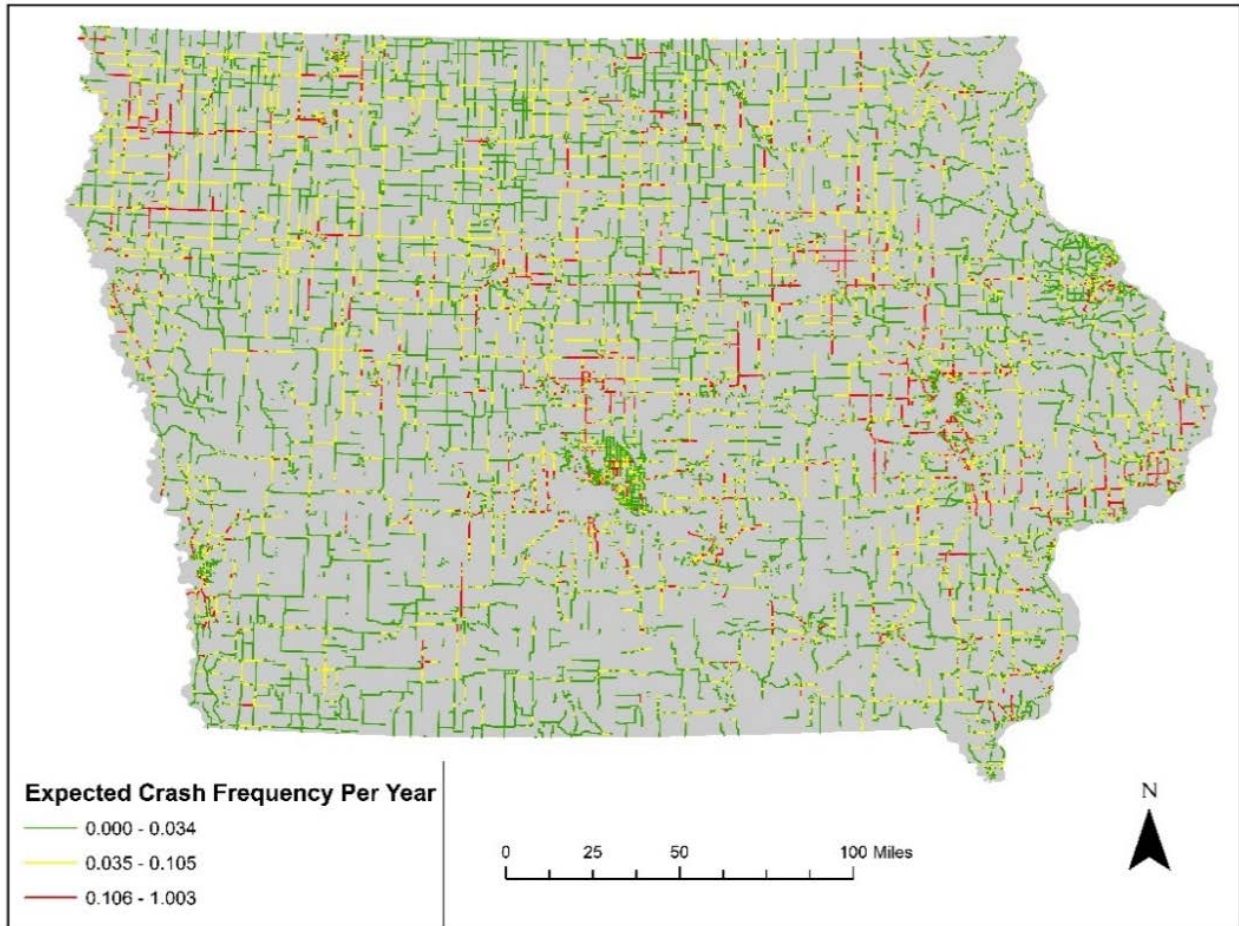


Figure 20. Expected centerline-related crashes per year

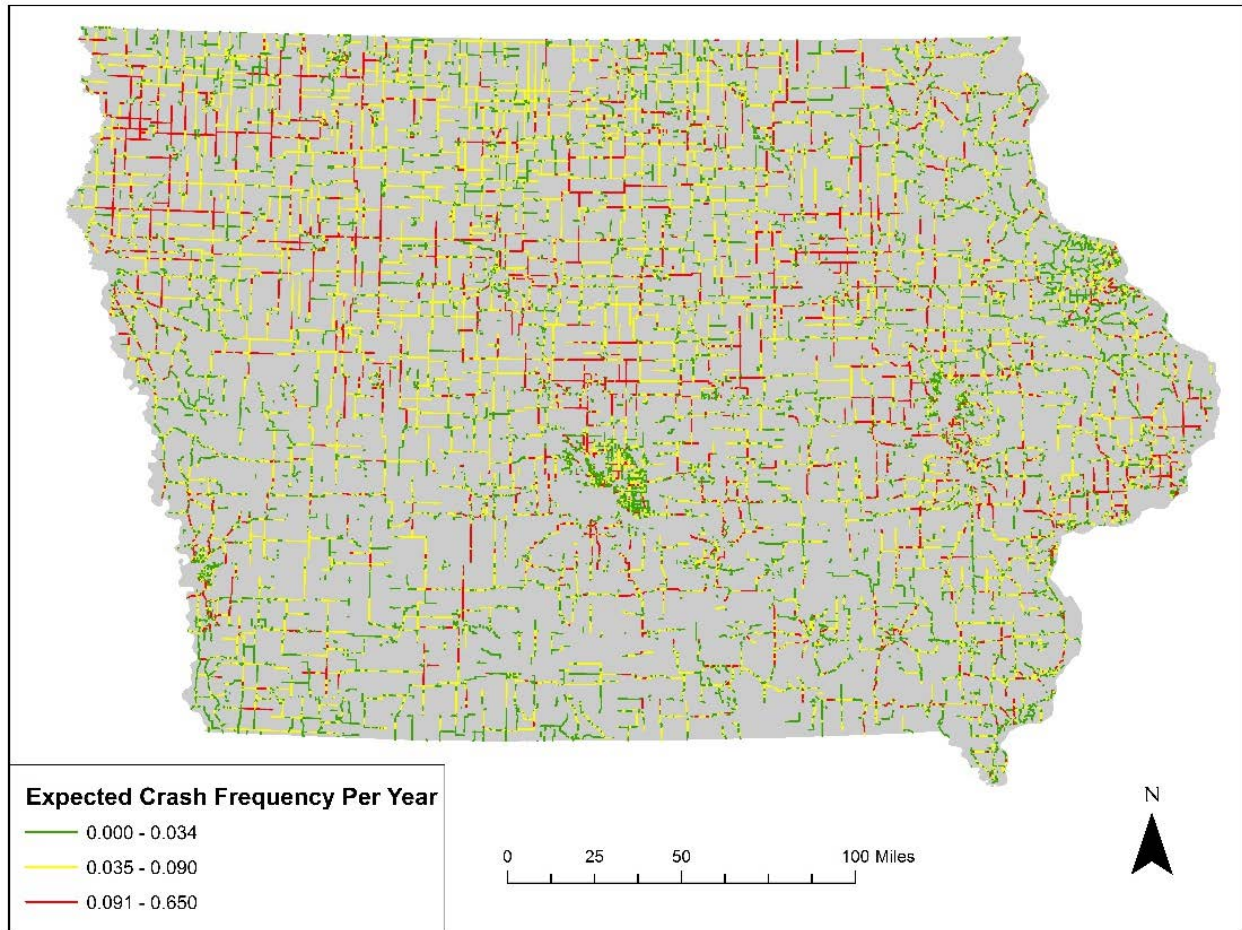


Figure 21. Expected edgeline-related crashes per year

CHAPTER 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 and the geographic dispersion of counties and data collection sites are shown as Figure 22.

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

A site summary of each data collection location is included in the 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/ELRS 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 13.

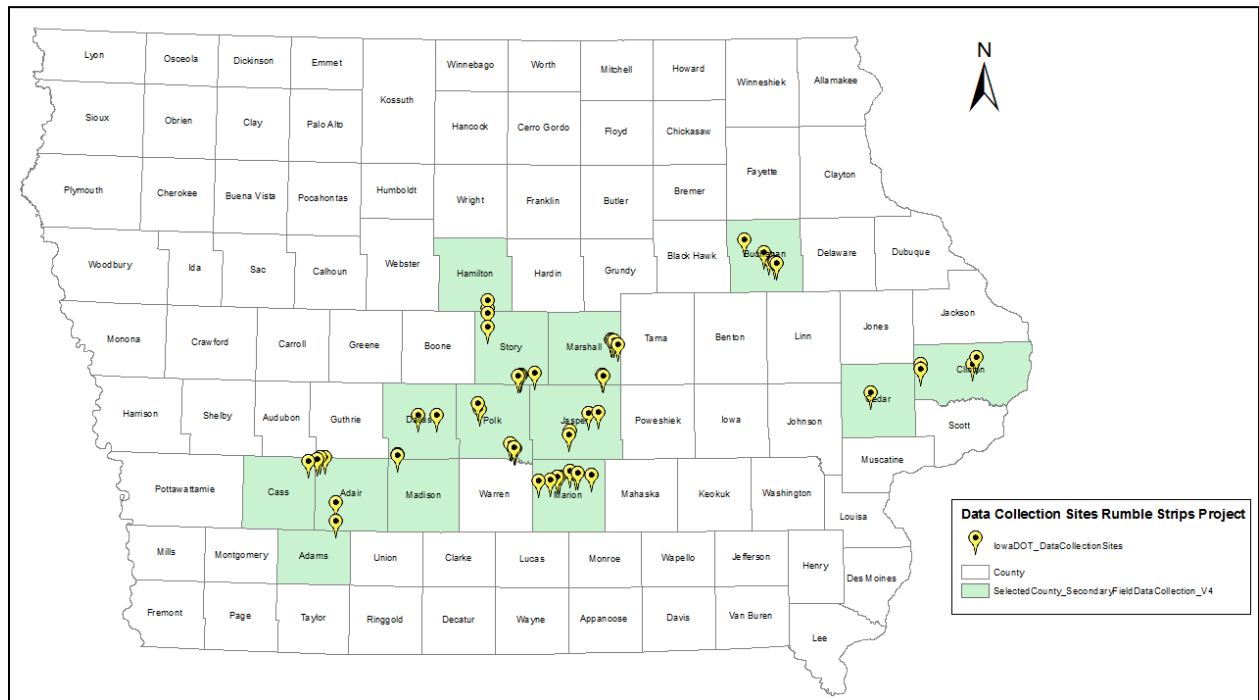


Figure 22. Data collection sites for field studies of driver behavior in Iowa, 2016

Table 13. 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 14.

Table 14. 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*	F28	<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

Table 14. continued

County	Roadway	Length (miles)	Lane Width (ft.)	Paved Shoulder Width (ft.)	Total Shoulder Width (ft.)	Rumble Strip Type	CLRS Length (in.)	SRS Length (in.)
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 or PV-13) <https://iowadot.gov/design/SRP/IndividualStandards/epv012.pdf> and <https://iowadot.gov/design/SRP/IndividualStandards/epv013.pdf>

** Rumble strip installation only on curved segments

Based on the responses collected from the county 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 23 displays the locations of the known rumble strip installations from the county engineer survey.

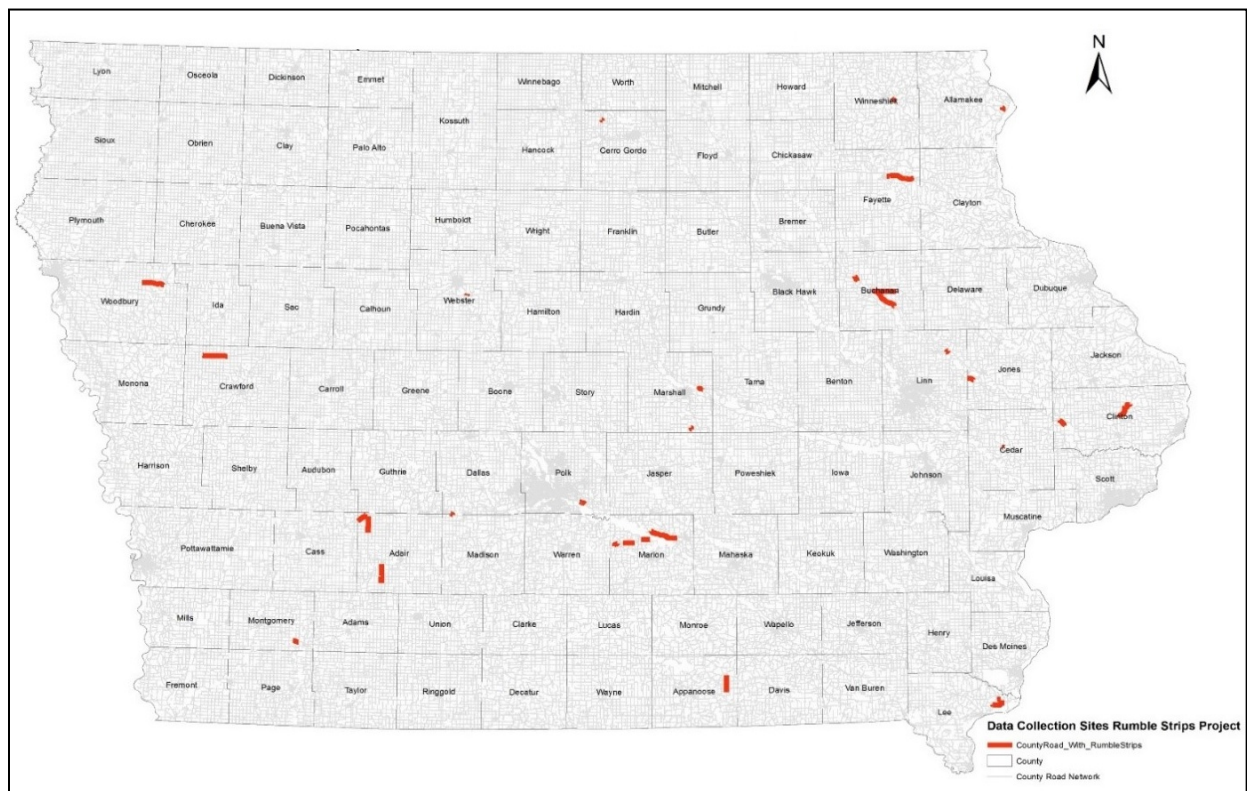


Figure 23. Rumble strip installations on secondary roadway system

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. Due to limited number of secondary network sites with rumble strips, primary roads were used to fill in gaps for various lane and shoulder width combinations. Out of 53 total data collection sites, 16 locations were selected along primary roadways to fill in the gaps in terms of lane and shoulder width combinations that were missing on the secondary roadway system. Table 15 shows the frequency of data collection at locations with specific characteristics related to speed limit, lane width, average paved shoulder width, and average gravel shoulder width.

Table 15. Frequency of locations with specific roadway characteristics

Segment Type	Treatment Type	Count	Lane Width (ft.)			Average Paved Shoulder Width (ft.)								Non-paved Shoulder Width (ft.)				
			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 24 shows the data collection trailer on the inside of a horizontal curve after initial set up with the required components installed.

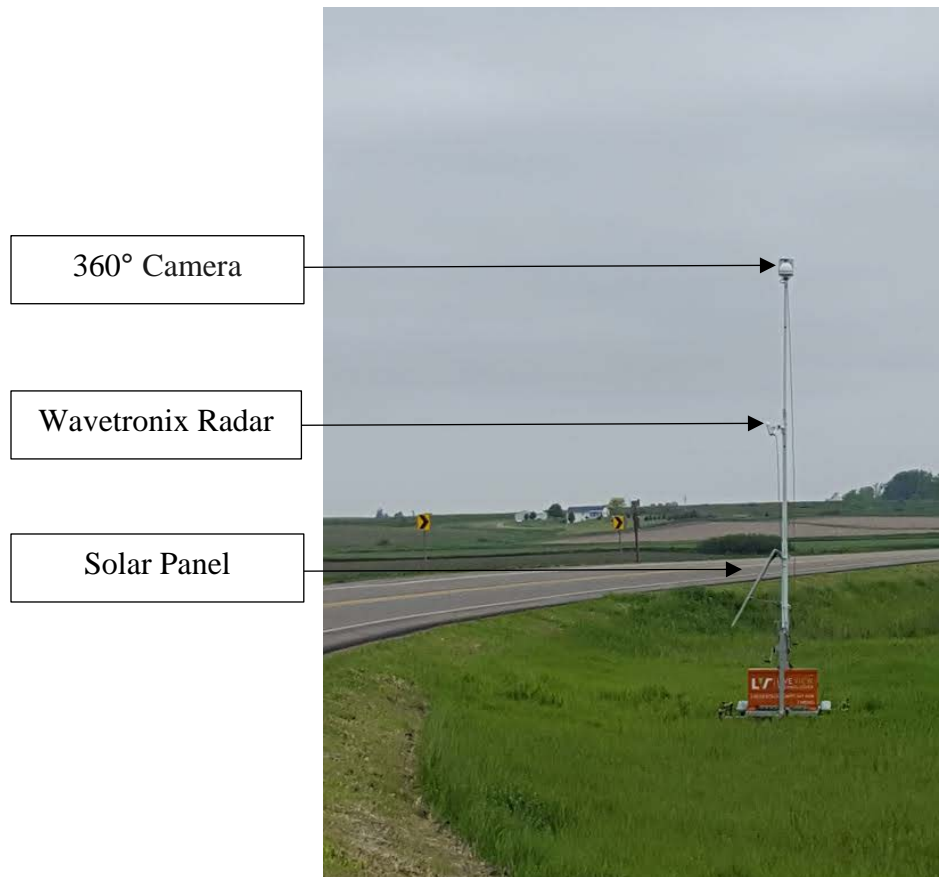


Figure 24. Data collection trailer components

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. Descriptive statistic summary of rumble strips dimensions are provided in Table 16. Descriptive statistic summary of dimensions of rumble strips characteristics at each site, such as lane width, shoulder width, and other dimensions were collected using the form illustrated in

Figure 25 Site summaries of the characteristics for each data collection location are included in Appendix A. Unfortunately, appropriate means to measure the rumble strips depth were not available in order to be able to measure the depth with the accuracy of less than half inches; however, according to the data collection crews' observations, most installations

followed the Iowa DOT Standard Road Plan (PV-12 or PV-13) suggestion for the depth of the rumble strips which is between 3/8 and 1/2 inch.

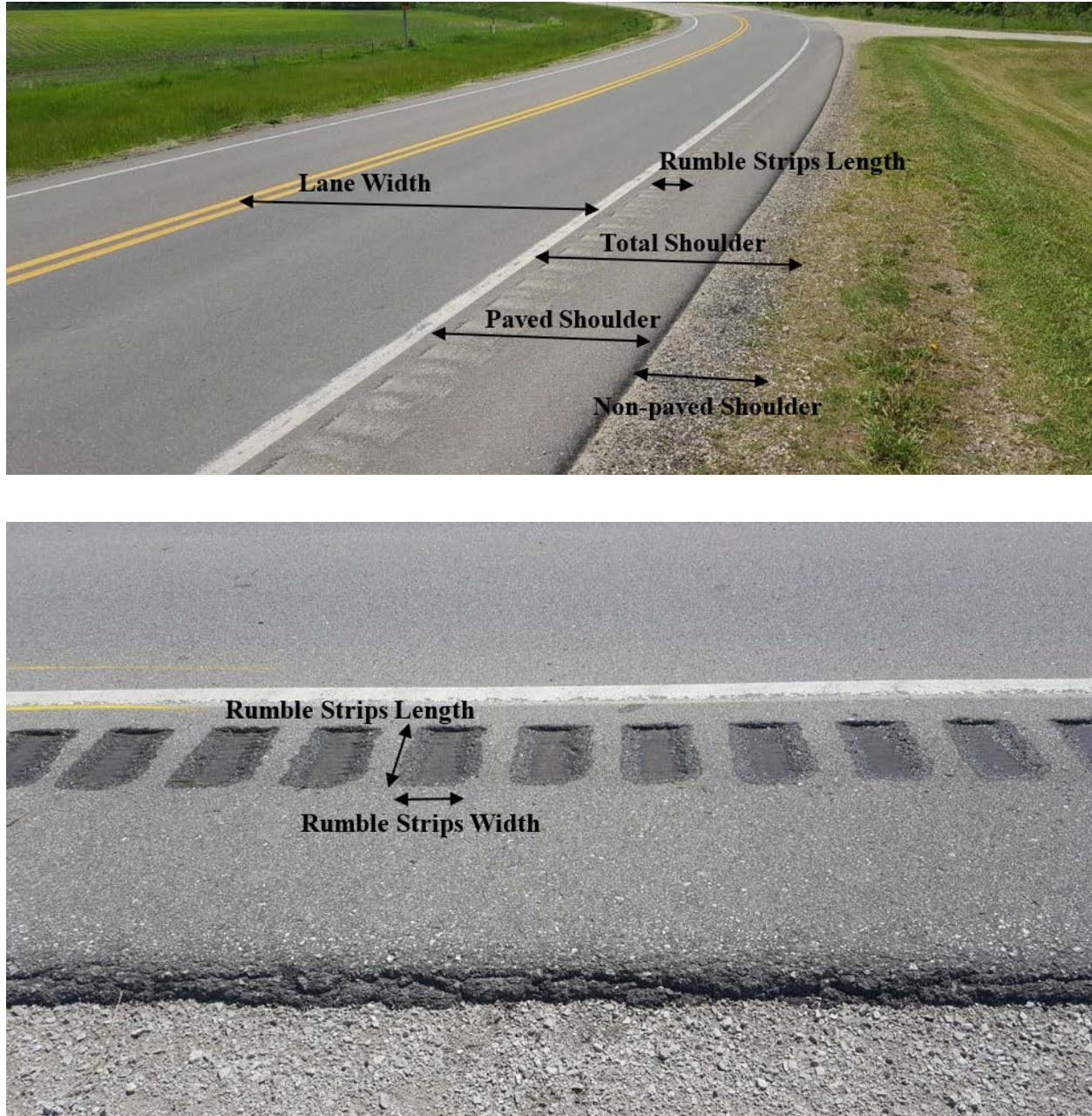


Figure 25. Data collection roadway measurements

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 26.

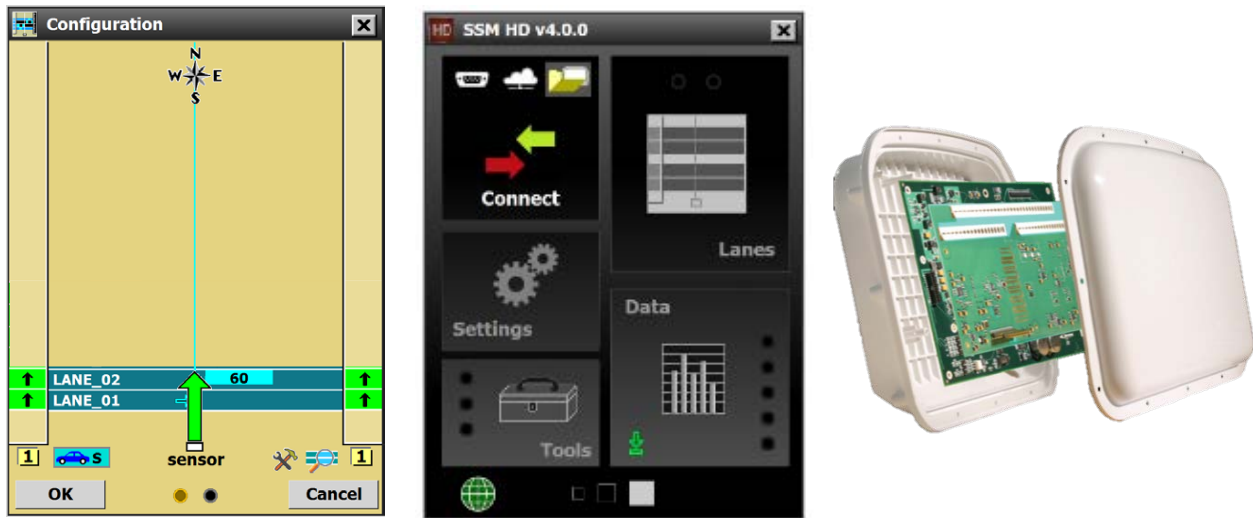
Table 16. Descriptive statistic summary of dimensions of rumble strips

Type of Rumble Strips	Rumble Strips dimensions	Range (in.)	Minimum (in.)	Maximum (in.)	Mean (in.)	Standard Deviation (in.)
CLRS and SRS	Near RS Width	2.00	6.00	8.00	7.36	0.66
	Near RS Length	2.00	12.00	14.00	12.61	0.77
	Near RS Spacing	1.00	12.00	13.00	12.43	0.49
	Far RS Width	8.00	0.00	8.00	6.19	2.60
	Far RS Length	14.00	0.00	14.00	10.90	4.57
	Far RS Spacing	14.00	0.00	14.00	10.69	4.46
	Center RS Width	1.00	6.00	7.00	6.33	0.47
	Center RS Length	5.00	11.00	16.00	15.31	1.73
	Center RS to RS Spacing	2.00	11.00	13.00	12.50	0.74
	Center Pair to Pair Spacing	13.00	25.00	38.00	35.13	4.71
CLRS-only	Near RS Width	0.00	0.00	0.00	0.00	0.00
	Near RS Length	0.00	0.00	0.00	0.00	0.00
	Near RS Spacing	0.00	0.00	0.00	0.00	0.00
	Far RS Width	0.00	0.00	0.00	0.00	0.00
	Far RS Length	0.00	0.00	0.00	0.00	0.00
	Far RS Spacing	0.00	0.00	0.00	0.00	0.00
	Center RS Width	3.00	6.00	9.00	7.24	1.04
	Center RS Length	1.00	6.00	7.00	6.23	0.42
	Center RS to RS Spacing	1.00	13.00	14.00	13.23	0.42
	Center Pair to Pair Spacing	0.00	0.00	0.00	0.00	0.00
SRS-only	Near RS Width	10.00	0.00	10.00	6.82	1.41
	Near RS Length	17.00	0.00	17.00	10.31	4.17
	Near RS Spacing	15.00	0.00	15.00	12.64	1.64
	Far RS Width	7.00	5.00	12.00	7.36	1.35
	Far RS Length	13.00	4.00	17.00	10.39	3.93
	Far RS Spacing	5.00	9.00	14.00	12.43	1.18
	Center RS Width	0.00	0.00	0.00	0.00	0.00
	Center RS Length	0.00	0.00	0.00	0.00	0.00
	Center RS to RS Spacing	0.00	0.00	0.00	0.00	0.00
	Center Pair to Pair Spacing	0.00	0.00	0.00	0.00	0.00

PERSONNEL AND EQUIPMENT						
Personnel					Site Number	
Trailer						
Equipment						
SETUP DETAILS						
Coordinates						
Roadway						
Nearest Town/City						
Start Time/Date						
Weather						
End Time/Date						
Weather						
MEASUREMENTS						
Near Side			Centerline			SITE SKETCH
Type	Value	Unit	Type	Value	Unit	
RS Width		Inches	RS Width		Inches	
RS Length		Inches	RS Length		Inches	
RS Spacing		Inches	RS to RS Spacing		Inches	
Gravel Shoulder Width		Feet	Pair to Pair Spacing		Inches	
RS to Edge of Pavement		Feet	Trailer			
RS to Edge Line		Feet	Type	Value	Unit	
Edge Line to Edge of Pavement		Feet	To Edge of Pavement		Feet	
Cardinal Direction			To Edgeline		Feet	
Roadway Direction			To Rumble Strip		Feet	
			To Centerline		Feet	
Far Side			Roadway			
Type	Value	Unit	Type	Value	Unit	
RS Width		Inches	Edgeline to Edgeline		Feet	
RS Length		Inches	Edge of Pavement to Edge of Pavement		Feet	
RS Spacing		Inches	Rumble Strip to Rumble Strip		Feet	
Gravel Shoulder Width		Feet	Facility Type			
RS to Edge of Pavement		Feet	Passing Allowed			
RS to Edge Line		Feet	Near Side Posted Speed Limit		MPH	
Edge Line to Edge of Pavement		Feet	Far Side Posted Speed Limit		MPH	
Cardinal Direction			Segment Type			
Roadway Direction						

Figure 26. 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 27. For further information, Wavetronix use manual instruction can be found in <https://www.wavetronix.com/en/support/downloads/494-smartsensor-hd-user-guide>. After the team left the data collection location, the installed devices were routinely monitored remotely to ensure accuracy during the data collection period. Further information regarding the.



* Picture Source: Smart Sensor HD user guide, Wavetronix.

Figure 27. Screenshots of the lane configuration program (left), 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 28 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 28. 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 29 contains two video review instances where it was difficult to determine if a particular roadway attribute was crossed during the video recording.



Figure 29. 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.

Another minor limitation was an inability to compare the results from the sensor to video logs under nighttime conditions. The resolution quality of the camera was low under dark conditions and, thus, the final dataset did not include any vehicles travelling during the night.

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 30.



Figure 30. 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. Figure 31 shows all sites where data collection group went to and collected required data split into two categories based upon whether or not the data have been used for analysis purposes.

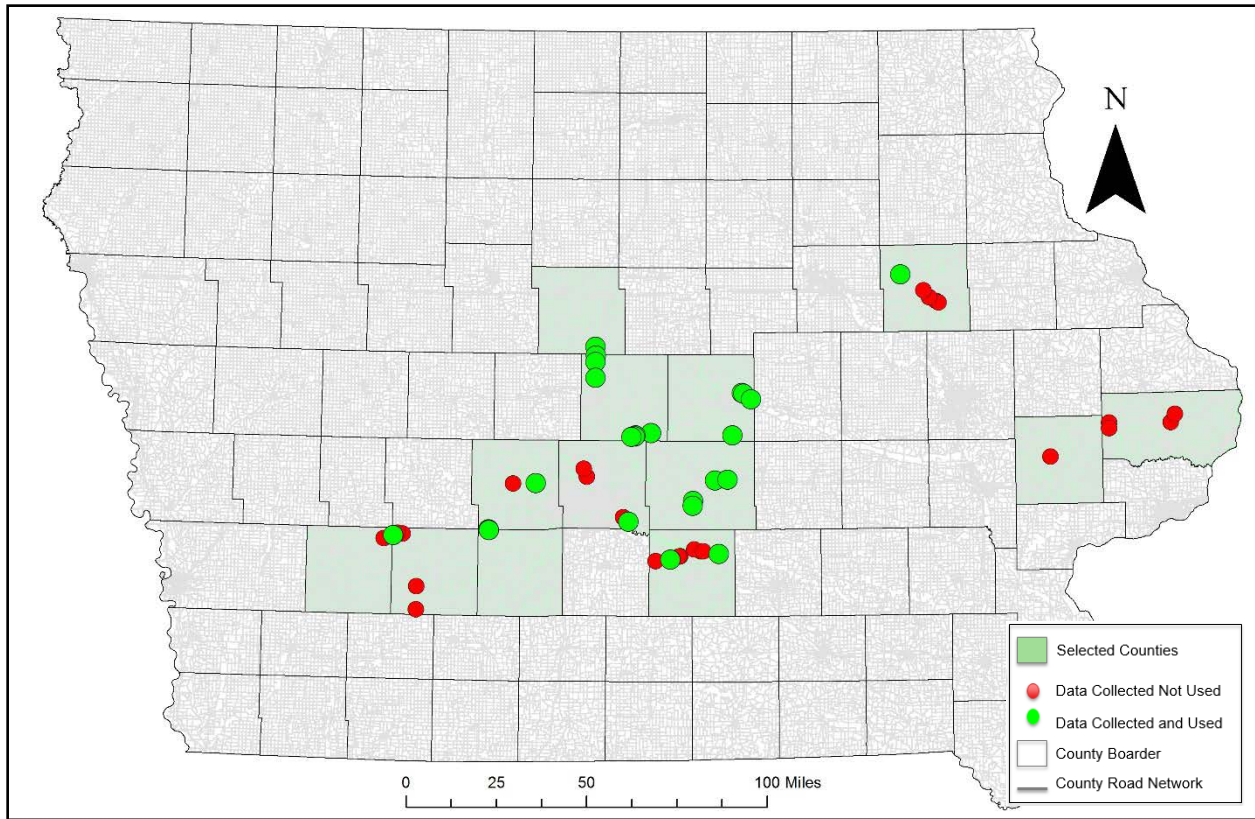


Figure 31. Rumble strips operation data collection sites (used or not used in analysis)

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 17 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 17. Observations by lane

Characteristic	Near Lane		Far Lane	
	Count	Percent	Count	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%
55 MPH Speed Limit	14,840	77.24%	21,753	80.94%
50 MPH Speed Limit	1,869	9.73%	1,821	6.78%
45 MPH Speed Limit	2,503	13.03%	3,301	12.28%
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 encroaches 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 18 and Table 19.

Table 18. 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 Only Rumble Strips	-0.725	0.258	-2.816	0.00487
Edgeline Only Rumble Strips	-0.710	0.313	-2.269	0.02326

Table 19. 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 Only Rumble Strips	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 20 and Table 21, respectively.

Table 20. 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 with 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 21. 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 18 and Table 19 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 be most likely to occur on segments with narrow 10-ft. lanes.

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 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.

4.5.4 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.

CHAPTER 5: PUBLIC 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 32 shows the spatial distribution of the surveyed cities, while Figure 33 shows the spatial distribution of the survey participants.

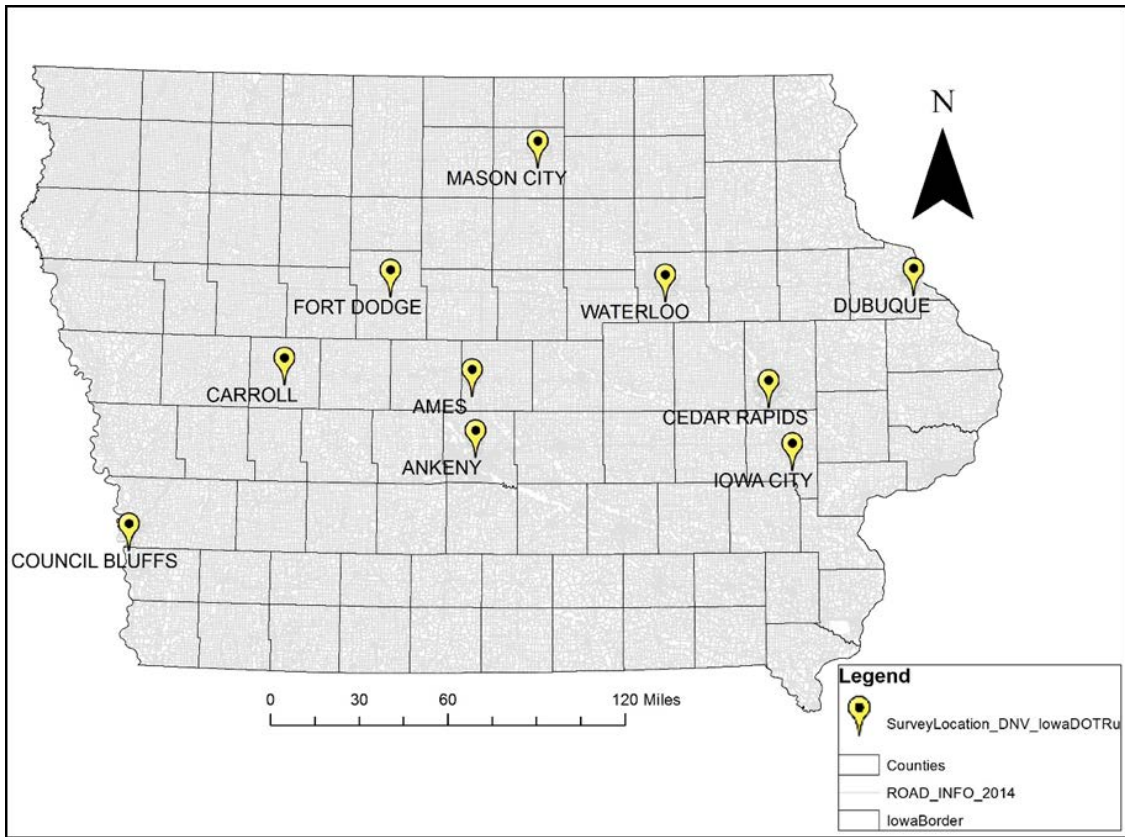


Figure 32. Spatial distribution of survey locations

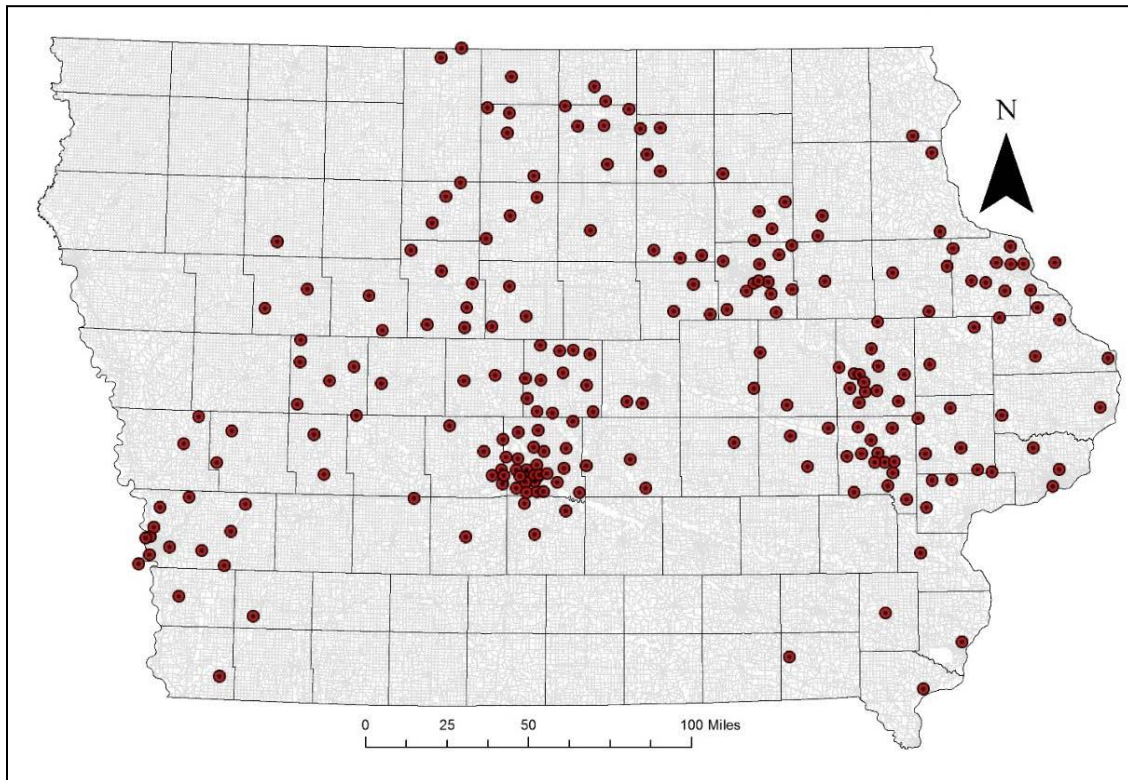


Figure 33. Spatial distribution of survey participants

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 22.

Table 22. 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 the 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 the 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 Public 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 raises 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. 95% of those survey participants who live near a two-lane highway where rumble strips had been installed (11% of all survey participants) think rumble strips provide sufficient feedback and approximately 85% of those respondents support the continued installation of rumble strips on

two-lane highway. 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 ever bike on a two-lane highway with rumble strips in place, half of them think presence of rumble strips might create problems for bicyclists. Likewise, while 87% had not walked or jogged on such roadways, less than 20% of those who ever walk or jog on such roadways think presence of rumble strips may create a problem 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 all respondents who live near a two-lane highway with rumble strips installed, given the fact that those respondents live in the vicinity of two-lane highways, the rate of those who bike and jog increase to 38%, and 28% respectively. It should be noted that only 18% and 11% of those respondents who live near a two-lane highway with rumble strips installed feel rumble strips create a problem 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. Summary of key findings associated with the public survey are summarized as shown in the Table 23.

Table 23. Conclusions from public survey

Survey Results Categories	Description	Percentage	
Familiarity and Experience	Percentage of respondents who were familiar with rumble strips	95%	
	Percentage of respondents who had driven over rumble strips	91%	
	Special Driving Condition	1. Temporarily distracted	27%
		2. Adverse weather conditions	26%
		3. Tired or fatigued	19%
1. Nighttime driving		15%	
Secondary Impacts of Rumble Strips	Percentage of respondents who think rumble strips did not limit passing opportunities	68%	
	Percentage of respondents who think rumble strips did not impact speed selection	64%	
	Percentage of respondents who think rumble strips create issues for bicyclists	15%	
	Percentage of respondents who think rumble strips create issues for pedestrians	6%	
	Percentage of respondents who think rumble strip-related noise is an issue	10%	
Conclusions from Survey	Percentage of respondents who felt rumble strips provide sufficient feedback	92%	
	Percentage of respondents who would like to see further installations on two-lane highways	89%	

CHAPTER 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. The crash prediction models developed on the primary network as a part of this study were calibrated for use with the secondary network, as well. 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, as well as 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, which could potentially benefit the most from rumble strip installation.

Figure 34 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. 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.

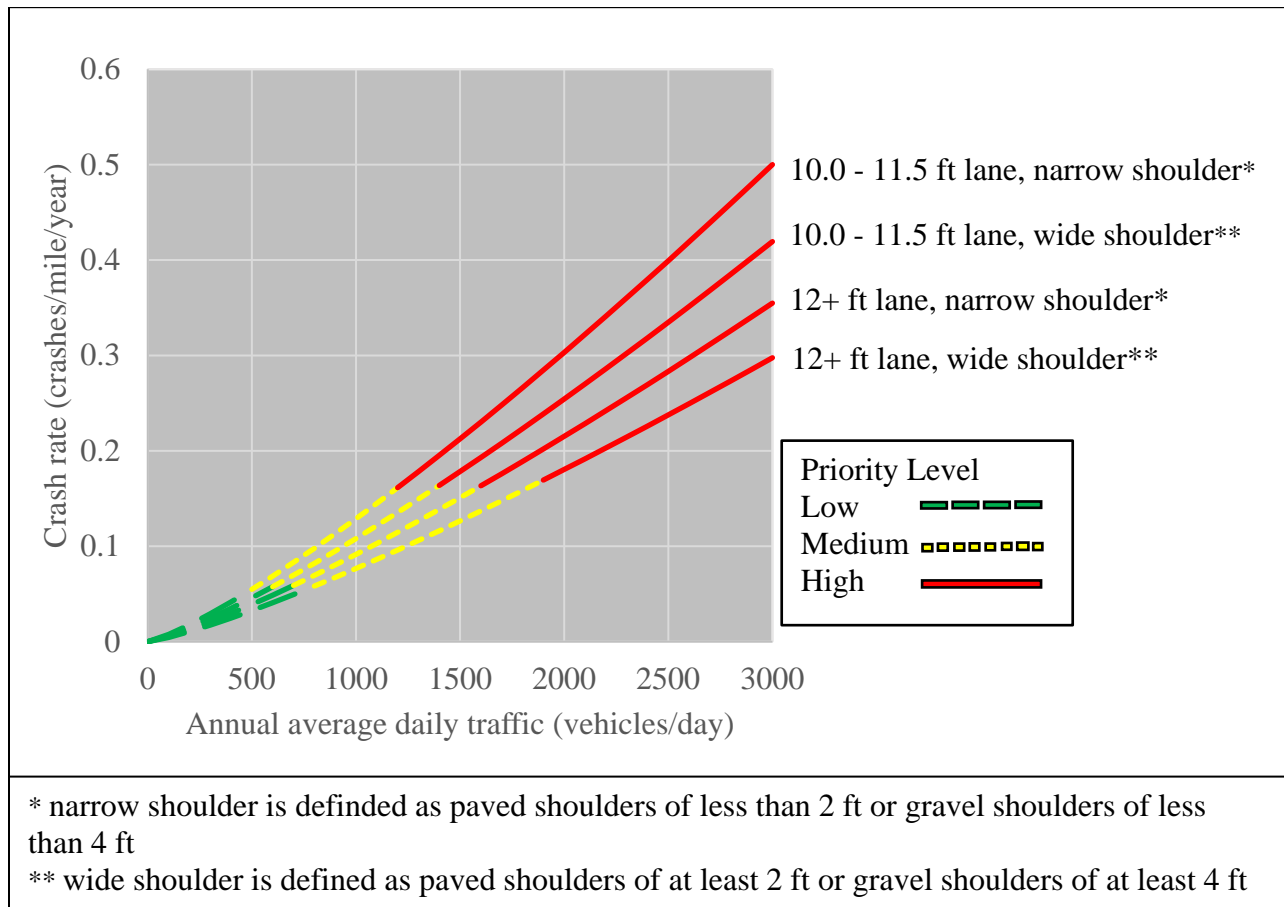


Figure 34. Centerline rumble strip installation priority

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

The expected rate of edgeline-related crashes was shown to vary widely depending on the specific geometric configuration of the roadway. Lanes that were narrower than 12 ft. in width, particularly those with narrow shoulders (less than 2 ft. paved or less than 4 ft. gravel) generally experience the highest rate of edgeline-related crashes. Figure 35 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. In contrast, segments with wider, 12-ft. lanes and wider shoulders do not experience a similar edgeline-related crash rate until traffic volumes

reach 2100 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.

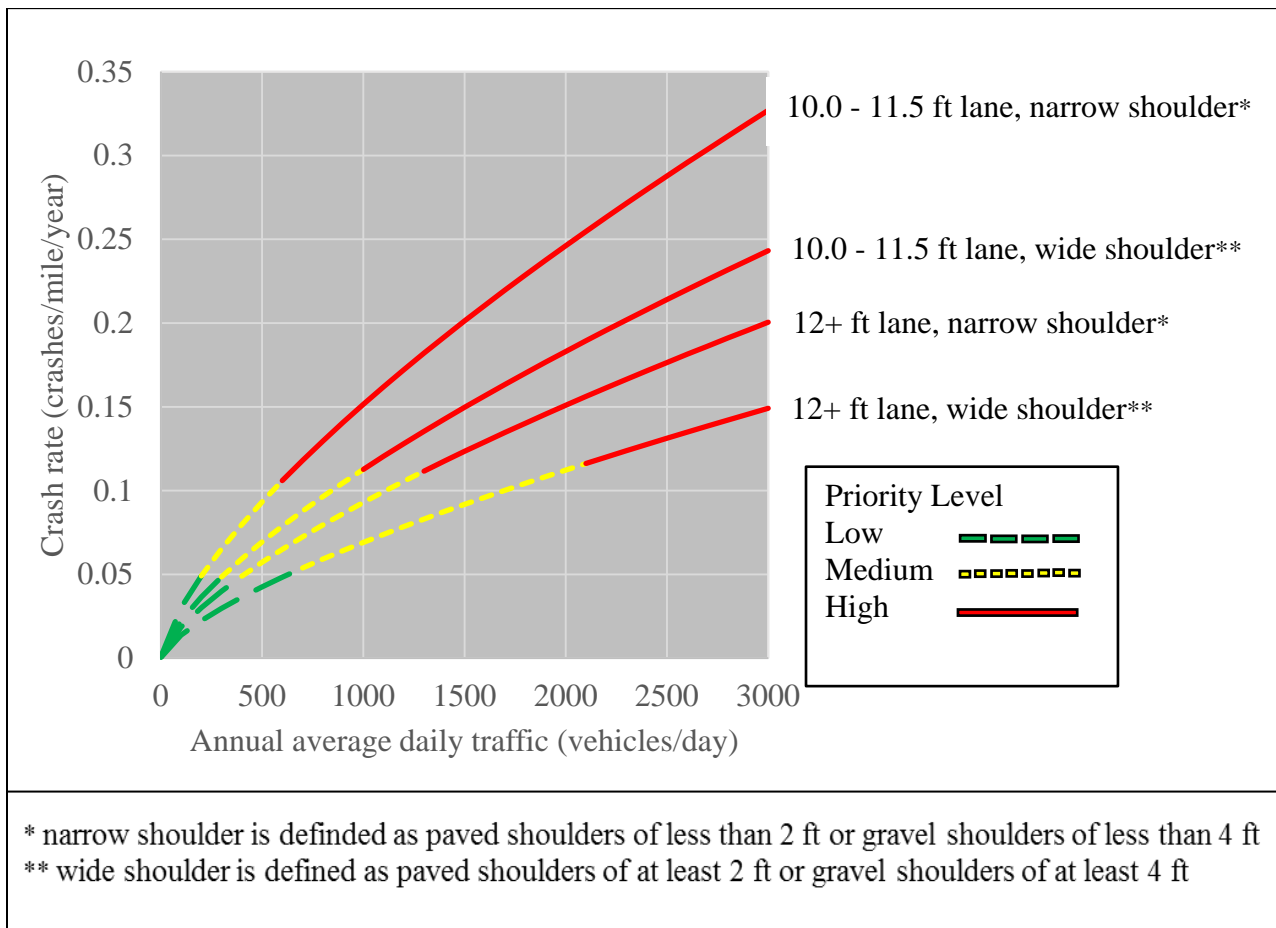


Figure 35. Edgeline/shoulder rumble strip installation priority

Figure 34 and Figure 35 provide a detailed prioritizations scheme which 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 24 provides unit costs for rumble strip installation on a per-mile basis from the Iowa DOT. The installation costs were obtained from the Bid Express which is a secure internet bidding service which allows to access the detailed bid information from all agencies using this service from 2012 to 2017. Historical low, average and high prices for rumble strips installation in a variety of formats, including by proposal, by item and by contractor were available through this service.

Table 24. 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 25 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 25. 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 SPF's 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 26, which shows cross-centerline target crashes to generally be more severe and, therefore, more costly.

Table 26. 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 36 through Figure 39 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 percent:

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

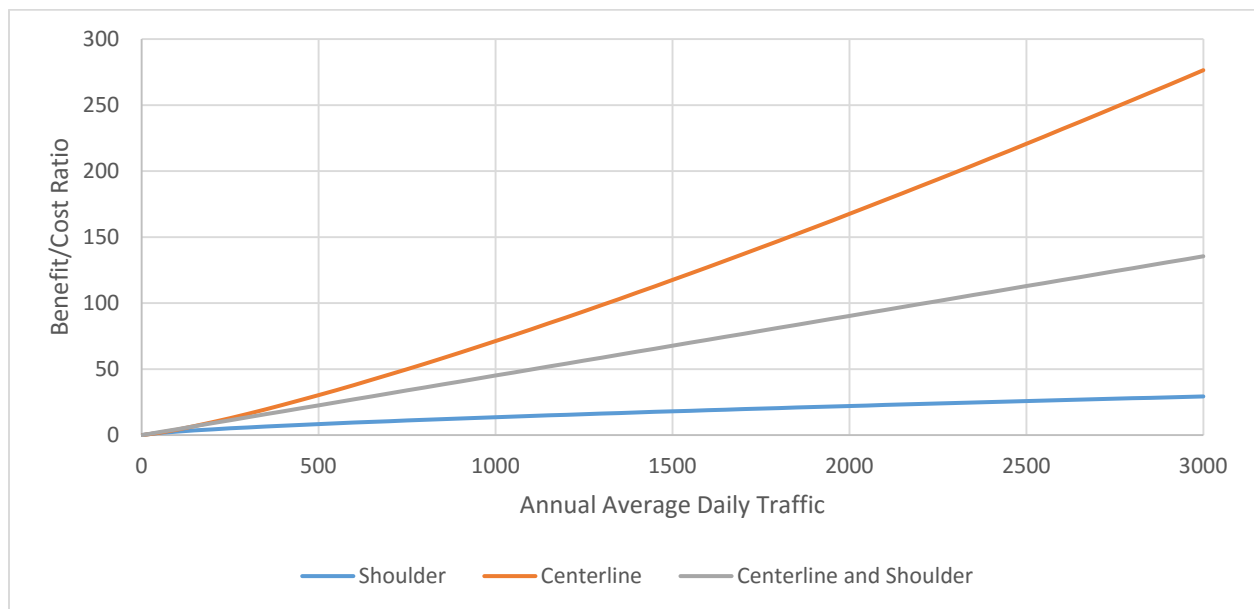


Figure 36. Benefit/cost ratios for rumble strip installations versus annual average daily traffic: lane width less than 12 ft, paved shoulder less than 2 ft or gravel shoulder less than 4 ft

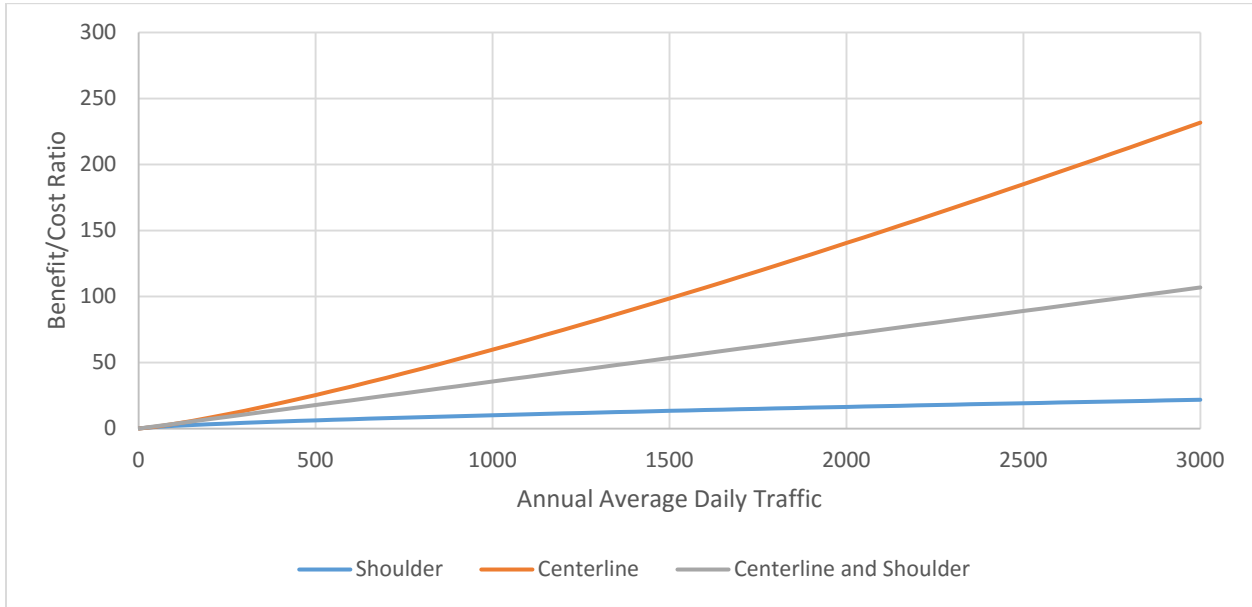


Figure 37. Benefit/cost ratios for rumble strip installations versus annual average daily traffic:
lane widths less than 12 ft, minimum 2 ft paved shoulder or 4 ft gravel shoulder

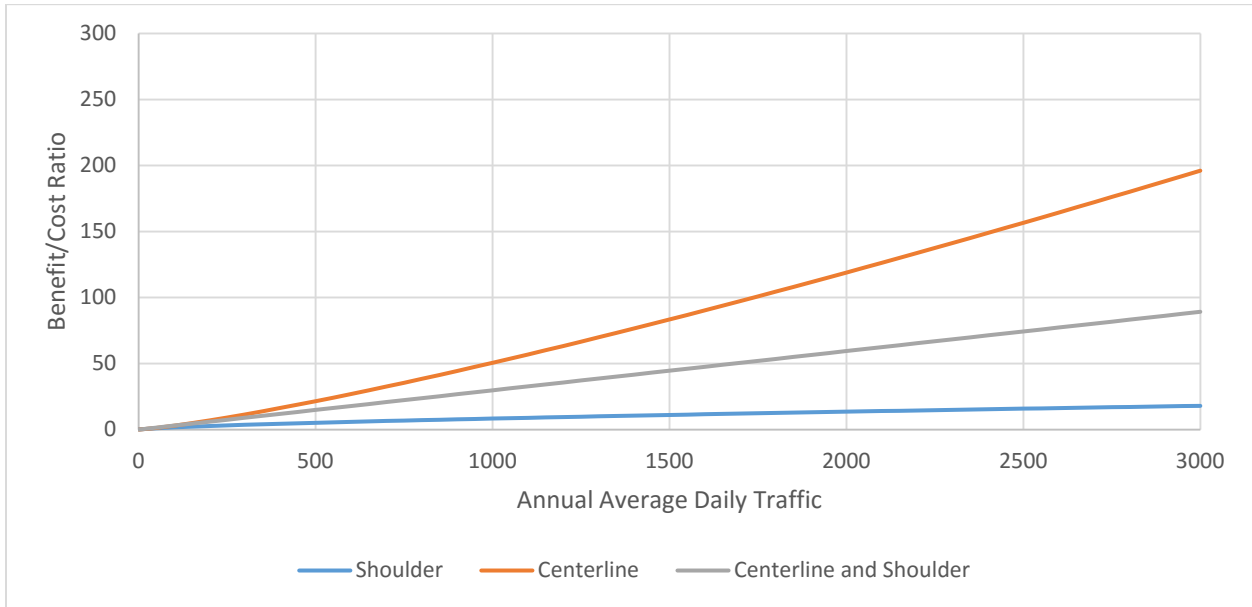


Figure 38. Benefit/cost ratios for rumble strip installations versus annual average daily traffic:
12 ft lanes, paved shoulder less than 2 ft or gravel shoulder less than 4 ft

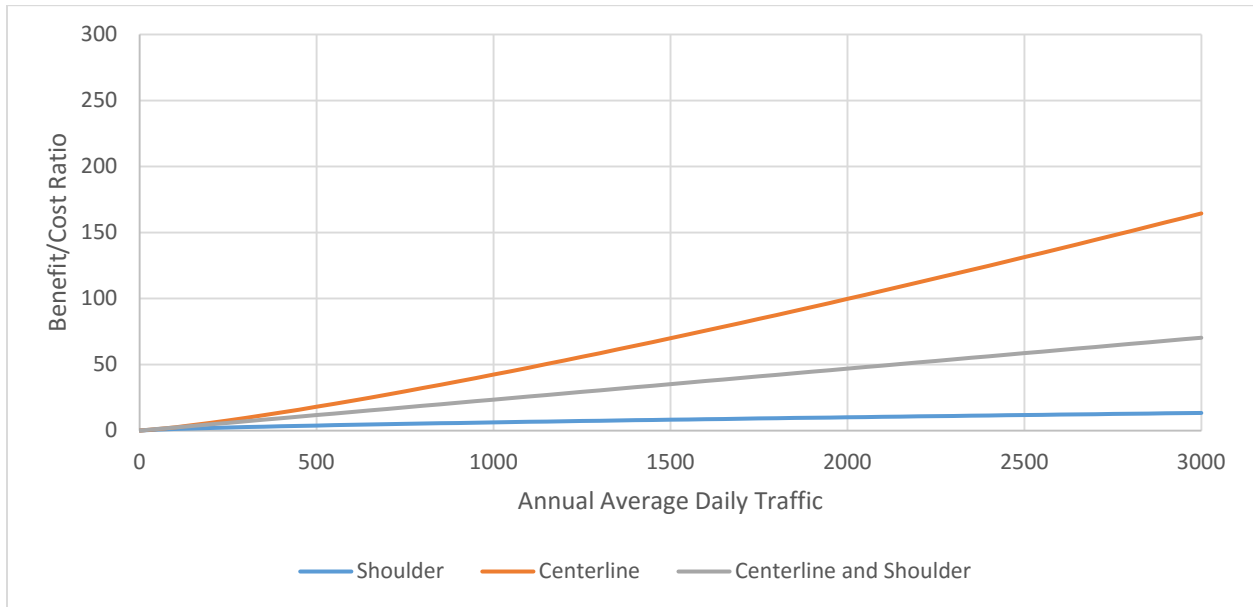


Figure 39. Benefit/cost ratios for rumble strip installations versus annual average daily traffic:
12 ft lanes, minimum 2 ft paved shoulder or 4 ft gravel shoulder

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.

6.4 Support from Field Studies of Road User Behavior

The results of the crash analysis 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, which 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 as it relates to the frequency of incidental contact by motorists under normal driving conditions. In particular, segments with lower posted speed limits, narrower lanes, 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 40 and Figure 41, respectively. Overall, these probabilities are quite small, suggesting 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.

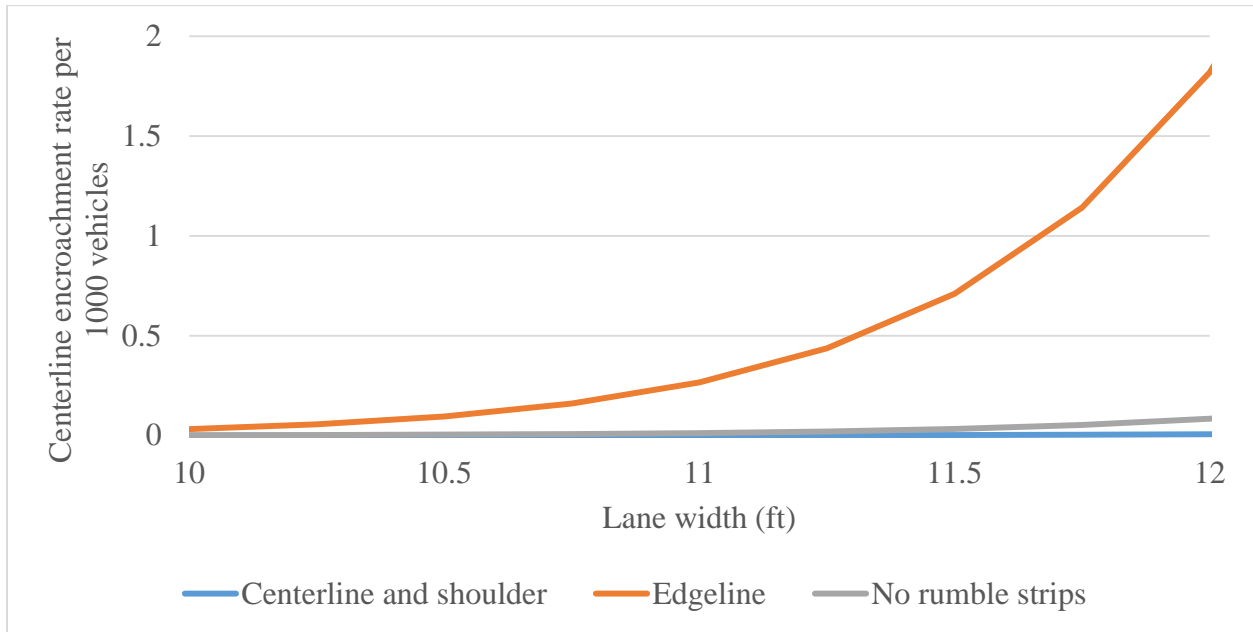


Figure 40. Centerline encroachment probability by rumble strip installation type

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 increase with lane width, while the probability of centerline encroachment was also shown to be elevated in the presence of edgeline rumble strips. Due to the current rumble strip implementation across the state of Iowa, no 10 ft. pavements with edgeline rumble strips were identified. It is likely that centerline encroachment probability would be higher than estimated in this study on 10 ft. lanes with rumble strip installations, therefore, it is recommended that rumble strips be installed on the shoulder for these types of facilities.

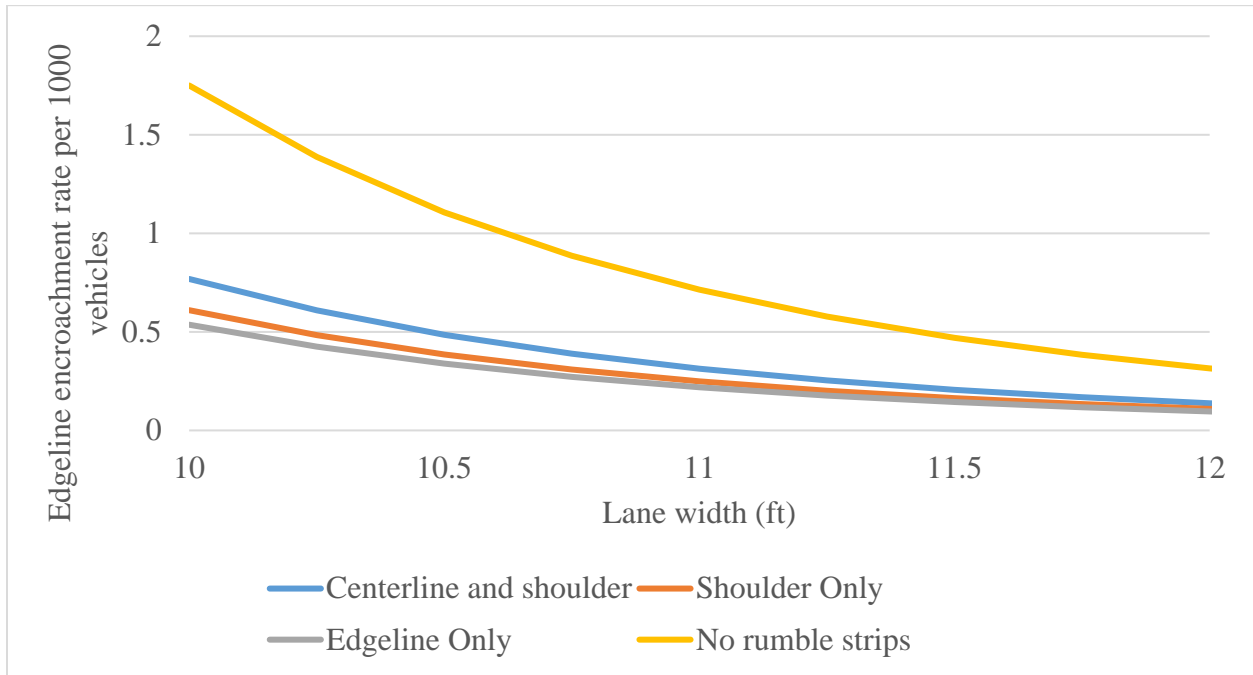


Figure 41. Edgeline encroachment probability by rumble strip installation type

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 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.

Beyond bicyclist concerns, another exception would be for those areas with relatively high levels of residential development where noise may be a great concern. This is particularly true for areas with higher truck volumes.

6.6 Study Limitations

Due to the lack of accurate rumble strip location data in the Iowa DOT roadway inventory files, only two years of crash data were available for analysis purposes. Ultimately, long-term safety performance trends could be discerned through an improved inventory system. It is also important to note that limited examples of rumble strip installation projects have occurred on the secondary roadway network to date. As several such projects are anticipated in the next few years, additional research will be warranted as much of the installation that has occurred across the country to date has been on higher functional class roadways. Coordination between the Iowa DOT and county road agencies would help facilitate such research.

6.7 Recommendation for Future Research

Overall, this research suggests that rumble strips are viable for installation over the vast majority of the two-lane undivided secondary roadway network. The findings of this study provide a starting point for continued installations on the secondary network. Once a sufficient number of such installations have occurred, follow-up research is recommended to assess short-term impacts on driver behavioral specifically on the secondary and local roadway network. This future research may also involve a more detailed safety evaluation on the secondary/local

networks, which would require a comprehensive inventory of the exact location of rumble strips installation on these networks.

For future research study in the realm of driver behavior, use of Lidar or detailed reviews of video data would provide useful sources of information to assess lateral positioning of vehicles at a greater level of fidelity as compared to the single point measurements of lateral position obtained using radar in this study. Using smaller scale, portable data collection devices would also provide a potential solution to the bias in the data that resulted when vehicles were found to shift away from the data collection trailer when it was located in close proximity to the roadway. Data on other important factors, such as vehicle type and the presence of opposing traffic, can also be investigated. Such detailed investigations may allow for a more detailed assessment of safety and operational differences between various site types.

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APPENDIX A

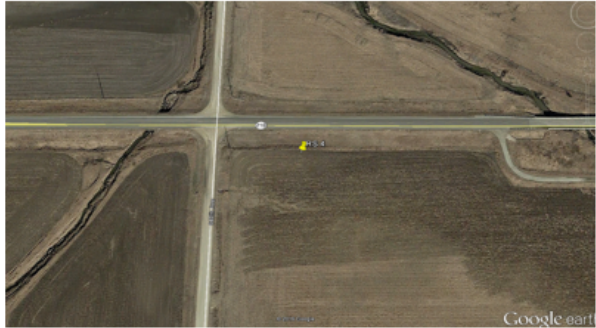
SUMMARY OF DATA COLLECTION LOCATIONS


PERSONNEL AND EQUIPMENT						
Personnel	Tim, Trevor, Ellen, Bijan, Abhinav, Skylar				Site Number	1
Trailer	TDC 00162					
Equipment	Wavetronix and LiDAR					
SETUP DETAILS						
Coordinates	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			Centerline			SITE SKETCH 
Type	Value	Unit	Type	Value	Unit	
RS Width	9	Inches	RS Width	NA	Inches	
RS Length	17	Inches	RS Length	NA	Inches	
RS Spacing	14	Inches	RS to RS Spacing	NA	Inches	
Gravel Shoulder Width	3	Feet	Pair to Pair Spacing	NA	Inches	
RS to Edge of Pavement	2.42	Feet	Trailer			
RS to Edge Line	0.7	Feet	Type	Value	Unit	
Edge Line to Edge of Pavement	2.22	Feet	To Edge of Pavement	31.5	Feet	
Cardinal Direction	E		To Edgeline	33.72	Feet	
Roadway Direction	EB		To Rumble Strip	33.92	Feet	
Far Side			To Centerline	44.22	Feet	
Type	Value	Unit	Roadway			
RS Width	7	Inches	Type	Value	Unit	
RS Length	17	Inches	Edgeline to Edgeline	21	Feet	
RS Spacing	14	Inches	Edge of Pavement to Edge of Pavement	26	Feet	
Gravel Shoulder Width	3	Feet	Rumble Strip to Rumble Strip	21	Feet	
RS to Edge of Pavement	3.42	Feet	Facility Type	2U		
RS to Edge Line	0.75	Feet	Passing Allowed	Far		
Edge Line to Edge of Pavement	2.78	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	


PERSONNEL AND EQUIPMENT							
Personnel	Tim, Trevor, Ellen, Bijan, Abhinav, Skylar					Site Number	2
Tractor	TDC 00164						
Equipment	Wavetronix						
SETUP DETAILS							
Coordinates	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			SITE SKETCH	
Type	Value	Unit	Type	Value	Unit	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.	
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		
			Roadway				
Type	Value	Unit	Type	Value	Unit		
RS Width	12	Inches	Edgeline to Edgeline	22.5	Feet		
RS Length	6	Inches	Edge of Pavement to Edge of Pavement	30.25	Feet		
RS Spacing	12	Inches	Rumble Strip to Rumble Strip	23.83	Feet		
Gravel Shoulder Width	2	Feet	Facility Type	2U			
RS to Edge of Pavement	3.17	Feet	Passing Allowed	No			
RS to Edge Line	0.5	Feet	Near Side Posted Speed Limit	55	MPH		
Edge Line to Edge of Pavement	3.5	Feet	Far Side Posted Speed Limit	55	MPH		
Cardinal Direction	NE		Segment Type	Curve	Treatment		
Roadway Direction	EB						





PERSONNEL AND EQUIPMENT							
Personnel	Grant, Trevor					Site Number	3
Trailer	TDC 00162						
Equipment	Wavetronix						
SETUP DETAILS							
Coordinates	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			Centerline			SITE SKETCH	
Type	Value	Unit	Type	Value	Unit	Notes: Chevrons located along the outside of the curve. 	
RS Width	7	Inches	RS Width	6	Inches		
RS Length	12	Inches	RS Length	16	Inches		
RS Spacing	13	Inches	RS to RS Spacing	12	Inches		
Gravel Shoulder Width	1.5	Feet	Pair to Pair Spacing	25	Inches		
RS to Edge of Pavement	4.33	Feet	Trailer				
RS to Edge Line	0.75	Feet	Type	Value	Unit		
Edge Line to Edge of Pavement	5.08	Feet	To Edge of Pavement	28.25	Feet		
Cardinal Direction	SW		To Edgeline	33.42	Feet		
Roadway Direction	WB		To Rumble Strip	32.58	Feet		
Far Side			To Centerline	44.33	Feet		
			Roadway				
Type	Value	Unit	Type	Value	Unit		
RS Width	8	Inches	Edgeline to Edgeline	22	Feet		
RS Length	12	Inches	Edge of Pavement to Edge of Pavement	32.33	Feet		
RS Spacing	14	Inches	Rumble Strip to Rumble Strip	23.67	Feet		
Gravel Shoulder Width	2.5	Feet	Facility Type	2U			
RS to Edge of Pavement	4.25	Feet	Passing Allowed	No			
RS to Edge Line	0.92	Feet	Near Side Posted Speed Limit	55	MPH		
Edge Line to Edge of Pavement	5.17	Feet	Far Side Posted Speed Limit	55	MPH		
Cardinal Direction	NE		Segment Type	Curve	Treatment		
Roadway Direction	EB						

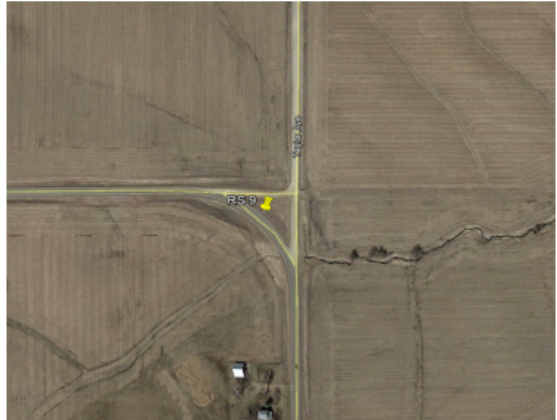
PERSONNEL AND EQUIPMENT						
Personnel	Trevor, Grant				Site Number	4
Trailer	TDC 00164					
Equipment	Wavetronix					
SETUP DETAILS						
Coordinates	41°52'39.05"N, 93°25'28.86"W					
Roadway	IA-210					
Nearest Town/City	Maxwell					
Start Time/Date	7/14/2016 14:45					
Weather	Sunny					
End Time/Date	7/15/2016 12:00					
Weather	Sunny					
MEASUREMENTS						
Near Side			Centerline			SITE SKETCH
Type	Value	Unit	Type	Value	Unit	
RS Width	NA	Inches	RS Width	NA	Inches	<p>Notes: This is a control section (no rumble strips present).</p> 
RS Length	NA	Inches	RS Length	NA	Inches	
RS Spacing	NA	Inches	RS to RS Spacing	NA	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	2.92	Feet	To Edge of Pavement	27	Feet	
Cardinal Direction	E		To Edgeline	29.75	Feet	
Roadway Direction	EB		To Rumble Strip	NA	Feet	
			To Centerline	41	Feet	
Far Side			Roadway			
Type	Value	Unit	Type	Value	Unit	
RS Width	NA	Inches	Edgeline to Edgeline	23	Feet	
RS Length	NA	Inches	Edge of Pavement to Edge of Pavement	28	Feet	
RS Spacing	NA	Inches	Rumble Strip to Rumble Strip	NA	Feet	
Gravel Shoulder Width	3	Feet	Facility Type	2U		
RS to Edge of Pavement	NA	Feet	Passing Allowed	Both		
RS to Edge Line	NA	Feet	Near Side Posted Speed Limit	55	MPH	
Edge Line to Edge of Pavement	2.67	Feet	Far Side Posted Speed Limit	55	MPH	
Cardinal Direction	W		Segment Type	Tangent	Control	
Roadway Direction	WB					


PERSONNEL AND EQUIPMENT							
Personnel	Tim, Trevor, Ellen, Bijan, Abhinav, Skylar					Site Number	5
Trailer	TDC 00162						
Equipment	Wavetronix						
SETUP DETAILS							
Coordinates	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			SITE SKETCH	
Type	Value	Unit	Type	Value	Unit	Intermittent rumble strips on shoulders 	
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		
Far Side			Roadway				
Type	Value	Unit	Type	Value	Unit		
RS Width	8	Inches	Edge Line to Edgeline	22.5	Feet		
RS Length	13	Inches	Edge of Pavement to Edge of Pavement	32.67	Feet		
RS Spacing	12	Inches	Rumble Strip to Rumble Strip	24.67	Feet		
Gravel Shoulder Width	3	Feet	Facility Type	2U			
RS to Edge of Pavement	4.16	Feet	Passing Allowed	No			
RS to Edge Line	1.16	Feet	Near Side Posted Speed Limit	55	MPH		
Edge Line to Edge of Pavement	5.75	Feet	Far Side Posted Speed Limit	55	MPH		
Cardinal Direction	NW		Segment Type	Curve	Treatment		
Roadway Direction	NB						


PERSONNEL AND EQUIPMENT							
Personnel	Tim, Trevor					Site Number	6
Trailer	TDC 00164						
Equipment	Wavetronix and LiDAR						
SETUP DETAILS							
Coordinates	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 Fahrenheit						
End Time/Date	6/1/2016 9:00						
Weather	Sunny						
MEASUREMENTS							
Near Side			Centerline			SITE SKETCH	
Type	Value	Unit	Type	Value	Unit	Intermittent rumble strips, LiDAR located 4.25 feet closer to the road than the Wavetronix 	
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		
			To Centerline	41.33	Feet		
Far Side			Roadway				
Type	Value	Unit	Type	Value	Unit		
RS Width	8	Inches	Edgeline to Edgeline	27.83	Feet		
RS Length	13	Inches	Edge of Pavement to Edge of Pavement	32.5	Feet		
RS Spacing	12	Inches	Rumble Strip to Rumble Strip	24.75	Feet		
Gravel Shoulder Width	3.5	Feet	Facility Type	2U			
RS to Edge of Pavement	4.25	Feet	Passing Allowed	Both			
RS to Edge Line	1	Feet	Near Side Posted Speed Limit	55	MPH		
Edge Line to Edge of Pavement	0.42	Feet	Far Side Posted Speed Limit	55	MPH		
Cardinal Direction	N		Segment Type	Tangent	Treatment		
Roadway Direction	NB						


PERSONNEL AND EQUIPMENT							
Personnel	Tim, Trevor, Bijan, Abhinav					Site Number	7
Trailer	TDC 00164						
Equipment	Wavetronix and LiDAR						
SETUP DETAILS							
Coordinates	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			Centerline			SITE SKETCH	
Type	Value	Unit	Type	Value	Unit	<p>Intermittent rumble strips</p> 	
RS Width	8	Inches	RS Width	7	Inches		
RS Length	14	Inches	RS Length	16	Inches		
RS Spacing	12	Inches	RS to RS Spacing	12	Inches		
Gravel Shoulder Width	4	Feet	Pair to Pair Spacing	37	Inches		
RS to Edge of Pavement	3.58	Feet	Trailer				
RS to Edge Line	0.833	Feet	Type	Value	Unit		
Edge Line to Edge of Pavement	4.5	Feet	To Edge of Pavement	27	Feet		
Cardinal Direction	S		To Edgeline	31.42	Feet		
Roadway Direction	SB		To Rumble Strip	30.6	Feet		
Far Side			To Centerline	43.5	Feet		
			Roadway				
Type	Value	Unit	Type	Value	Unit		
RS Width	7	Inches	Edgeline to Edgeline	23.58	Feet		
RS Length	14	Inches	Edge of Pavement to Edge of Pavement	32.17	Feet		
RS Spacing	13	Inches	Rumble Strip to Rumble Strip	25.33	Feet		
Gravel Shoulder Width	4	Feet	Facility Type	2U			
RS to Edge of Pavement	4.1	Feet	Passing Allowed	Both			
RS to Edge Line	1.08	Feet	Near Side Posted Speed Limit	55	MPH		
Edge Line to Edge of Pavement	4.08	Feet	Far Side Posted Speed Limit	55	MPH		
Cardinal Direction	N		Segment Type	Tangent	Treatment		
Roadway Direction	NB						


PERSONNEL AND EQUIPMENT							
Personnel	Tim, Trevor, Bijan, Abhinav					Site Number	8
Trailer	TDC 00162						
Equipment	Wavetronix						
SETUP DETAILS							
Coordinates	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			SITE SKETCH	
Type	Value	Unit	Type	Value	Unit	<p>Intermittent rumble strips</p> 	
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		
			To Centerline	38	Feet		
Far Side			Roadway				
Type	Value	Unit	Type	Value	Unit		
RS Width	7	Inches	Edgeline to Edgeline	22.83	Feet		
RS Length	12	Inches	Edge of Pavement to Edge of Pavement	34.33	Feet		
RS Spacing	13	Inches	Rumble Strip to Rumble Strip	24.42	Feet		
Gravel Shoulder Width	2.67	Feet	Facility Type	2U			
RS to Edge of Pavement	4.83	Feet	Passing Allowed	Near			
RS to Edge Line	0.67	Feet	Near Side Posted Speed Limit	55	MPH		
Edge Line to Edge of Pavement	5.67	Feet	Far Side Posted Speed Limit	55	MPH		
Cardinal Direction	N		Segment Type	Tangent	Treatment		
Roadway Direction	NB						


PERSONNEL AND EQUIPMENT							
Personnel	Tim, Ellen, Bijan, Abhinav					Site Number	9
Trailer	TDC 00162						
Equipment	Wavetronix						
SETUP DETAILS							
Coordinates	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 Fahrenheit						
End Time/Date	6/5/2016 11:00						
Weather	Sunny						
MEASUREMENTS							
Near Side			Centerline			SITE SKETCH	
Type	Value	Unit	Type	Value	Unit	<p>Intermittent rumble strips on inside of curve only</p> 	
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		
Far Side			Roadway				
Type	Value	Unit	Type	Value	Unit		
RS Width	8	Inches	Edgeline to Edgeline	21.83	Feet		
RS Length	12	Inches	Edge of Pavement to Edge of Pavement	26.83	Feet		
RS Spacing	13	Inches	Rumble Strip to Rumble Strip	20.83	Feet		
Gravel Shoulder Width	1	Feet	Facility Type	2U			
RS to Edge of Pavement	3	Feet	Passing Allowed	No			
RS to Edge Line	0.75	Feet	Near Side Posted Speed Limit	55	MPH		
Edge Line to Edge of Pavement	3.17	Feet	Far Side Posted Speed Limit	55	MPH		
Cardinal Direction	SE		Segment Type	Curve	Treatment		
Roadway Direction	EB						


PERSONNEL AND EQUIPMENT							
Personnel	Tim, Ellen, Bijan, Abhinav					Site Number	10
Trailer	TDC 00164						
Equipment	Wavetronix and LiDAR						
SETUP DETAILS							
Coordinates	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 Fahrenheit						
End Time/Date	6/5/2016 12:00						
Weather	Sunny						
MEASUREMENTS							
Near Side			Centerline			SITE SKETCH	
Type	Value	Unit	Type	Value	Unit	Control section, no rumble strips 	
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		


PERSONNEL AND EQUIPMENT						
Personnel	Tim, Bijan, Abhinav					
Trailer	TDC 00164					
Equipment	Wavetronix and LiDAR					
					Site Number	11
SETUP DETAILS						
Coordinates	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			Centerline			SITE SKETCH
Type	Value	Unit	Type	Value	Unit	
RS Width	7	Inches	RS Width	NA	Inches	<p>Intermittent rumble strips</p> 
RS Length	13	Inches	RS Length	NA	Inches	
RS Spacing	12	Inches	RS to RS Spacing	NA	Inches	
Gravel Shoulder Width	2.5	Feet	Pair to Pair Spacing	NA	Inches	
RS to Edge of Pavement	3.83	Feet	Trailer			
RS to Edge Line	0.83	Feet	Type	Value	Unit	
Edge Line to Edge of Pavement	3.83	Feet	To Edge of Pavement	26.17	Feet	
Cardinal Direction	W		To Edgeline	30	Feet	
Roadway Direction	WB		To Rumble Strip	30	Feet	
			To Centerline	30.75	Feet	
Far Side			Roadway			
Type	Value	Unit	Type	Value	Unit	
RS Width	7	Inches	Edgeline to Edgeline	21.42	Feet	
RS Length	13	Inches	Edge of Pavement to Edge of Pavement	30.33	Feet	
RS Spacing	12	Inches	Rumble Strip to Rumble Strip	23	Feet	
Gravel Shoulder Width	4	Feet	Facility Type	2U		
RS to Edge of Pavement	3.5	Feet	Passing Allowed	Both		
RS to Edge Line	0.83	Feet	Near Side Posted Speed Limit	55	MPH	
Edge Line to Edge of Pavement	5.08	Feet	Far Side Posted Speed Limit	55	MPH	
Cardinal Direction	E		Segment Type	Tangent	Treatment	
Roadway Direction	EB					


PERSONNEL AND EQUIPMENT							
Personnel	Tim, Bijan, Abhinav					Site Number	12
Trailer	TDC 00162						
Equipment	Wavetronix						
SETUP DETAILS							
Coordinates	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			SITE SKETCH Intermittent rumble strips 	
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		
			To Centerline	42.58	Feet		
Far Side			Roadway				
Type	Value	Unit	Type	Value	Unit		
RS Width	7	Inches	Type	21	Feet		
RS Length	13	Inches	Edgeline to Edgeline	29.33	Feet		
RS Spacing	12	Inches	Edge of Pavement to Edge of Pavement	23.75	Feet		
Gravel Shoulder Width	2.5	Feet	Rumble Strip to Rumble Strip	2U			
RS to Edge of Pavement	3.25	Feet	Facility Type	No			
RS to Edge Line	1	Feet	Passing Allowed	55	MPH		
Edge Line to Edge of Pavement	3.83	Feet	Near Side Posted Speed Limit	55	MPH		
Cardinal Direction	S		Far Side Posted Speed Limit				
Roadway Direction	EB		Segment Type	Curve	Treatment		


PERSONNEL AND EQUIPMENT						
Personnel	Tim, Bijan, Abhinav, Trevor				Site Number	13
Trailer	TDC 00164					
Equipment	Wavetronix and LiDAR					
SETUP DETAILS						
Coordinates	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			SITE SKETCH
Type	Value	Unit	Type	Value	Unit	
RS Width	NA	Inches	RS Width	NA	Inches	Control section, no rumble strips 
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	
			To Centerline	31.42	Feet	
Far Side			Roadway			
Type	Value	Unit	Type	Value	Unit	
RS Width	NA	Inches	Edgeline to Edgeline	20.75	Feet	
RS Length	NA	Inches	Edge of Pavement to Edge of Pavement	22.25	Feet	
RS Spacing	NA	Inches	Rumble Strip to Rumble Strip	NA	Feet	
Gravel Shoulder Width	4	Feet	Facility Type	2U		
RS to Edge of Pavement	NA	Feet	Passing Allowed	Both		
RS to Edge Line	NA	Feet	Near Side Posted Speed Limit	55	MPH	
Edge Line to Edge of Pavement	0.75	Feet	Far Side Posted Speed Limit	55	MPH	
Cardinal Direction	W		Segment Type	Tangent	Control	
Roadway Direction	WB					


PERSONNEL AND EQUIPMENT						
Personnel	Tim, Bijan, Abhinav, Trevor				Site Number	14
Trailer	TDC 00162					
Equipment	Wavetronix					
SETUP DETAILS						
Coordinates	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			SITE SKETCH
Type	Value	Unit	Type	Value	Unit	
RS Width	NA	Inches	RS Width	NA	Inches	Control section, no rumble strips 
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	
			To Centerline	40	Feet	
Far Side			Roadway			
Type	Value	Unit	Type	Value	Unit	
RS Width	NA	Inches	Edgeline to Edgeline	20.67	Feet	
RS Length	NA	Inches	Edge of Pavement to Edge of Pavement	22	Feet	
RS Spacing	NA	Inches	Rumble Strip to Rumble Strip	NA	Feet	
Gravel Shoulder Width	4.5	Feet	Facility Type	2U		
RS to Edge of Pavement	NA	Feet	Passing Allowed	No		
RS to Edge Line	NA	Feet	Near Side Posted Speed Limit	50	MPH	
Edge Line to Edge of Pavement	0.42	Feet	Far Side Posted Speed Limit	50	MPH	
Cardinal Direction	N		Segment Type	Curve	Control	
Roadway Direction	NB					


PERSONNEL AND EQUIPMENT							
Personnel	Tim, Bijan, Abhinav, Trevor					Site Number	15
Trailer	TDC 00162						
Equipment	Wavetronix						
SETUP DETAILS							
Coordinates	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			Centerline			SITE SKETCH	
Type	Value	Unit	Type	Value	Unit		
RS Width	8	Inches	RS Width	6	Inches	<p>Intermittent rumble strips</p> 	
RS Length	12	Inches	RS Length	11	Inches		
RS Spacing	12	Inches	RS to RS Spacing	13	Inches		
Gravel Shoulder Width	0.92	Feet	Pair to Pair Spacing	38	Inches		
RS to Edge of Pavement	2.17	Feet	Trailer				
RS to Edge Line	0.83	Feet	Type	Value	Unit		
Edge Line to Edge of Pavement	2	Feet	To Edge of Pavement	61	Feet		
Cardinal Direction	N		To Edgeline	63	Feet		
Roadway Direction	NB		To Rumble Strip	62	Feet		
Far Side			To Centerline	74	Feet		
			Roadway				
Type	Value	Unit	Type	Value	Unit		
RS Width	7	Inches	Edge Line to Edgeline	23.17	Feet		
RS Length	12	Inches	Edge of Pavement to Edge of Pavement	28	Feet		
RS Spacing	12	Inches	Rumble Strip to Rumble Strip	24.83	Feet		
Gravel Shoulder Width	0.83	Feet	Facility Type	2U			
RS to Edge of Pavement	1.83	Feet	Passing Allowed	Far			
RS to Edge Line	0.83	Feet	Near Side Posted Speed Limit	55	MPH		
Edge Line to Edge of Pavement	2.83	Feet	Far Side Posted Speed Limit	55	MPH		
Cardinal Direction	S		Segment Type	Curve	Treatment		
Roadway Direction	SB						


PERSONNEL AND EQUIPMENT							
Personnel	Tim, Bijan, Abhinav, Trevor					Site Number	16
Trailer	TDC 00164						
Equipment	Wavetronix and LiDAR						
SETUP DETAILS							
Coordinates	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			Centerline			SITE SKETCH Intermittent rumble strips 	
Type	Value	Unit	Type	Value	Unit		
RS Width	6	Inches	RS Width	6	Inches		
RS Length	13	Inches	RS Length	16	Inches		
RS Spacing	12	Inches	RS to RS Spacing	13	Inches		
Gravel Shoulder Width	1.08	Feet	Pair to Pair Spacing	38	Inches		
RS to Edge of Pavement	1.83	Feet	Trailer				
RS to Edge Line	0.83	Feet	Type	Value	Unit		
Edge Line to Edge of Pavement	2.75	Feet	To Edge of Pavement	33.5	Feet		
Cardinal Direction	S		To Edgeline	36.25	Feet		
Roadway Direction	SB		To Rumble Strip	35.42	Feet		
			To Centerline	48	Feet		
Far Side			Roadway				
Type	Value	Unit	Type	Value	Unit		
RS Width	7	Inches	Edgeline to Edgeline	23	Feet		
RS Length	13	Inches	Edge of Pavement to Edge of Pavement	28	Feet		
RS Spacing	12	Inches	Rumble Strip to Rumble Strip	25.75	Feet		
Gravel Shoulder Width	9	Feet	Facility Type	2U			
RS to Edge of Pavement	1.67	Feet	Passing Allowed	Both			
RS to Edge Line	1.17	Feet	Near Side Posted Speed Limit	55	MPH		
Edge Line to Edge of Pavement	2.25	Feet	Far Side Posted Speed Limit	55	MPH		
Cardinal Direction	N		Segment Type	Tangent	Treatment		
Roadway Direction	NB						

PERSONNEL AND EQUIPMENT						
Personnel	Tim, Bijan, Abhinav, Trevor				Site Number	17
Trailer	TDC 00164					
Equipment	Wavetronix and LiDAR					
SETUP DETAILS						
Coordinates	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			SITE SKETCH 
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	
			To Centerline	41.33	Feet	
Far Side			Roadway			
Type	Value	Unit	Type	Value	Unit	
RS Width	5	Inches	Edgeline to Edgeline	23.67	Feet	
RS Length	15	Inches	Edge of Pavement to Edge of Pavement	32	Feet	
RS Spacing	9	Inches	Rumble Strip to Rumble Strip	26.75	Feet	
Gravel Shoulder Width	6	Feet	Facility Type	2U		
RS to Edge of Pavement	3.08	Feet	Passing Allowed	Both		
RS to Edge Line	0.92	Feet	Near Side Posted Speed Limit	55	MPH	
Edge Line to Edge of Pavement	4.00	Feet	Far Side Posted Speed Limit	55	MPH	
Cardinal Direction	W		Segment Type	Tangent	Treatment	
Roadway Direction	WB					

PERSONNEL AND EQUIPMENT						
Personnel	Tim, Bijan, Abhinav, Trevor				Site Number	18
Trailer	TDC 00162					
Equipment	Wavetronix					
SETUP DETAILS						
Coordinates	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 Fahrenheit					
End Time/Date	6/10/2016 12:00					
Weather	Sunny					
MEASUREMENTS						
Near Side			Centerline			SITE SKETCH 
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	
			To Centerline	37.58	Feet	
Far Side			Roadway			
Type	Value	Unit	Type	Value	Unit	
RS Width	6	Inches	Edgeline to Edgeline	22.67	Feet	
RS Length	15	Inches	Edge of Pavement to Edge of Pavement	31.83	Feet	
RS Spacing	13	Inches	Rumble Strip to Rumble Strip	25	Feet	
Gravel Shoulder Width	4	Feet	Facility Type	2U		
RS to Edge of Pavement	4.67	Feet	Passing Allowed	Far		
RS to Edge Line	1.25	Feet	Near Side Posted Speed Limit	55	MPH	
Edge Line to Edge of Pavement	4.83	Feet	Far Side Posted Speed Limit	55	MPH	
Cardinal Direction	W		Segment Type	Curve	Treatment	
Roadway Direction	WB					


PERSONNEL AND EQUIPMENT						
Personnel	Tim, Bijan, Trevor				Site Number	19
Trailer	TDC 00164					
Equipment	Wavetronix and LiDAR					
SETUP DETAILS						
Coordinates	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			Centerline			SITE SKETCH 
Type	Value	Unit	Type	Value	Unit	
RS Width	7	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	1.75	Feet	Trailer			
RS to Edge Line	0.75	Feet	Type	Value	Unit	
Edge Line to Edge of Pavement	2.42	Feet	To Edge of Pavement	22.42	Feet	
Cardinal Direction	W		To Edgeline	24.83	Feet	
Roadway Direction	WB		To Rumble Strip	24.17	Feet	
			To Centerline	36.5	Feet	
Far Side			Roadway			
Type	Value	Unit	Type	Value	Unit	
RS Width	7	Inches	Edgeline to Edgeline	23	Feet	
RS Length	5	Inches	Edge of Pavement to Edge of Pavement	27.25	Feet	
RS Spacing	13	Inches	Rumble Strip to Rumble Strip	24.42	Feet	
Gravel Shoulder Width	NA	Feet	Facility Type	2U		
RS to Edge of Pavement	1.58	Feet	Passing Allowed	Far		
RS to Edge Line	0.83	Feet	Near Side Posted Speed Limit	40	MPH	
Edge Line to Edge of Pavement	1.83	Feet	Far Side Posted Speed Limit	40	MPH	
Cardinal Direction	E		Segment Type	Tangent	Treatment	
Roadway Direction	EB					


PERSONNEL AND EQUIPMENT						
Personnel	Tim, Bijan, Trevor				Site Number	20
Trailer	TDC 00162					
Equipment	Wavetronix					
SETUP DETAILS						
Coordinates	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			SITE SKETCH 
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	

PERSONNEL AND EQUIPMENT						
Personnel	Tim, Bijan, Trevor, Abhinav				Site Number	21
Trailer	TDC 00164					
Equipment	Wavetronix and LiDAR					
SETUP DETAILS						
Coordinates	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 Fahrenheit					
End Time/Date	6/13/2016 9:00					
Weather	Sunny					
MEASUREMENTS						
Near Side			Centerline			SITE SKETCH Intermittent rumble strips 
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	

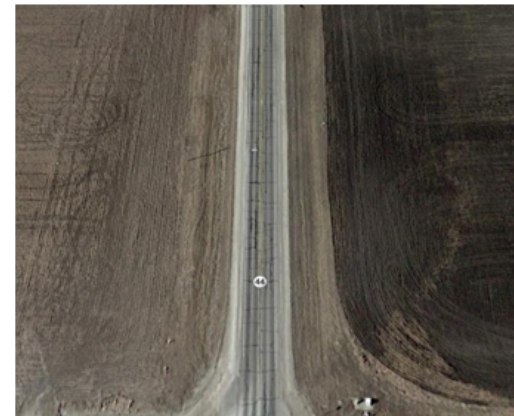
PERSONNEL AND EQUIPMENT						
Personnel	Tim, Bijan, Trevor, Abhinav				Site Number	22
Trailer	TDC 00164					
Equipment	Wavetronix and LiDAR					
SETUP DETAILS						
Coordinates	41°32'18.08"N, 93°26'38.86"W					
Roadway	F70					
Nearest Town/City	Pleasant Hill					
Start Time/Date	6/12/2016 11:15					
Weather	Sunny, 85 Degrees Farenheit					
End Time/Date	6/13/2016 10:00					
Weather	Sunny					
MEASUREMENTS						
Near Side			Centerline			SITE SKETCH
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	2.33	Feet	To Edge of Pavement	15.33	Feet	
Cardinal Direction	NW		To Edgeline	17.75	Feet	
Roadway Direction	NWB		To Rumble Strip	NA	Feet	
Far Side			To Centerline	29.25	Feet	
Type	Value	Unit	Roadway			
RS Width	NA	Inches	Type	Value	Unit	
RS Length	NA	Inches	Edgeline to Edgeline	23.75	Feet	
RS Spacing	NA	Inches	Edge of Pavement to Edge of Pavement	28.25	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	Near		
Edge Line to Edge of Pavement	2.42	Feet	Near Side Posted Speed Limit	40	MPH	
Cardinal Direction	SE		Far Side Posted Speed Limit	40	MPH	
Roadway Direction	SWB		Segment Type	Tangent	Control	




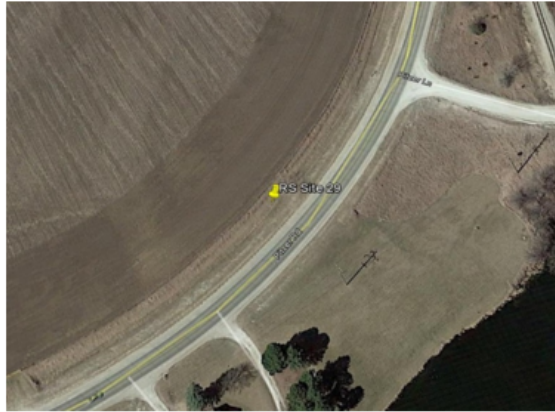
PERSONNEL AND EQUIPMENT						
Personnel	Tim, Bijan, Trevor			Site Number	23	
Trailer	TDC 00164					
Equipment	Wavetronix and LiDAR					
SETUP DETAILS						
Coordinates	41°43'5.37"N, 93°39'46.33"W					
Roadway	IA-415					
Nearest Town/City	Polk City					
Start Time/Date	6/13/2016					
Weather	Sunny, 87 Degrees Fahrenheit					
End Time/Date	6/16/2016 9:00					
Weather	Sunny					
MEASUREMENTS						
Near Side			Centerline			SITE SKETCH 
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	


PERSONNEL AND EQUIPMENT						
Personnel	Tim, Bijan, Trevor				Site Number	24
Trailer	TDC 00162					
Equipment	Wavetronix					
SETUP DETAILS						
Coordinates	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			SITE SKETCH 
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	


PERSONNEL AND EQUIPMENT						
Personnel	Tim, Bijan, Trevor, Abhinav				Site Number	27
Trailer	TDC 00164					
Equipment	Wavetronix and LiDAR					
SETUP DETAILS						
Coordinates	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			SITE SKETCH
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	
			To Centerline	49.5	Feet	
Far Side			Roadway			
Type	Value	Unit	Type	Value	Unit	
RS Width	NA	Inches	Edgeline to Edgeline	22.75	Feet	
RS Length	NA	Inches	Edge of Pavement to Edge of Pavement	32	Feet	
RS Spacing	NA	Inches	Rumble Strip to Rumble Strip	NA	Feet	
Gravel Shoulder Width	8.33	Feet	Facility Type	2U		
RS to Edge of Pavement	NA	Feet	Passing Allowed	No		
RS to Edge Line	NA	Feet	Near Side Posted Speed Limit	50	MPH	
Edge Line to Edge of Pavement	4.75	Feet	Far Side Posted Speed Limit	50	MPH	
Cardinal Direction	E		Segment Type	Tangent	Treatment	
Roadway Direction	EB					





PERSONNEL AND EQUIPMENT						
Personnel	Tim, Bijan, Trevor, Abhinav				Site Number	28
Trailer	TDC 00162					
Equipment	Wavetronix					
SETUP DETAILS						
Coordinates	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			SITE SKETCH 
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	


PERSONNEL AND EQUIPMENT						
Personnel	Grant, Bijan, Trevor, Abhinav				Site Number	29
Trailer	TDC 00162					
Equipment	Wavetronix					
SETUP DETAILS						
Coordinates	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			SITE SKETCH 
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	
			To Centerline	42.17	Feet	
Far Side			Roadway			
Type	Value	Unit	Type	Value	Unit	
RS Width	8	Inches	Edgeline to Edgeline	22.25	Feet	
RS Length	6	Inches	Edge of Pavement to Edge of Pavement	24	Feet	
RS Spacing	14	Inches	Rumble Strip to Rumble Strip	21.17	Feet	
Gravel Shoulder Width	6.17	Feet	Facility Type	2U		
RS to Edge of Pavement	0.75	Feet	Passing Allowed	No		
RS to Edge Line	0.25	Feet	Near Side Posted Speed Limit	55	MPH	
Edge Line to Edge of Pavement	0.75	Feet	Far Side Posted Speed Limit	55	MPH	
Cardinal Direction	N		Segment Type	Curve	Treatment	
Roadway Direction	NB					

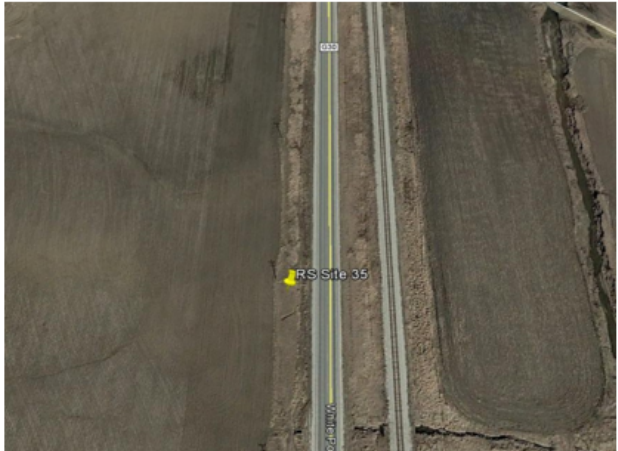
PERSONNEL AND EQUIPMENT						
Personnel	Grant, Bijan, Trevor, Abhinav				Site Number	30
Trailer	TDC 00164					
Equipment	Wavetronix and LiDAR					
SETUP DETAILS						
Coordinates	41°29'54.26"N, 94°11'6.09"W					
Roadway	P-53					
Nearest Town/City	Dexter					
Start Time/Date	6/17/2016 12:19					
Weather	Sunny					
End Time/Date	6/18/2016 10:00					
Weather	Sunny					
MEASUREMENTS						
Near Side			Centerline			SITE SKETCH 
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	


PERSONNEL AND EQUIPMENT						
Personnel	Ellen, Bijan, Tim				Site Number	31
Trailer	TDC 00164					
Equipment	Wavetronix and LiDAR					
SETUP DETAILS						
Coordinates	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			SITE SKETCH 
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	


PERSONNEL AND EQUIPMENT						
Personnel	Ellen, Bijan, Tim				Site Number	32
Trailer	TDC 00162					
Equipment	Wavetronix					
SETUP DETAILS						
Coordinates	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			SITE SKETCH 
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	


PERSONNEL AND EQUIPMENT						
Personnel	Ellen, Bijan, Trevor, Abhinav				Site Number	33
Trailer	TDC 00164					
Equipment	Wavetronix and LiDAR					
SETUP DETAILS						
Coordinates	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			SITE SKETCH 
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	
			Roadway			
Type	Value	Unit	Type	Value	Unit	
RS Width	6	Inches	Edgeline to Edgeline	21.42	Feet	
RS Length	12	Inches	Edge of Pavement to Edge of Pavement	26.83	Feet	
RS Spacing	12	Inches	Rumble Strip to Rumble Strip	23.25	Feet	
Gravel Shoulder Width	3	Feet	Facility Type	2U		
RS to Edge of Pavement	1.67	Feet	Passing Allowed	Near		
RS to Edge Line	1.17	Feet	Near Side Posted Speed Limit	55	MPH	
Edge Line to Edge of Pavement	2.75	Feet	Far Side Posted Speed Limit	55	MPH	
Cardinal Direction	S		Segment Type	Tangent	Treatment	
Roadway Direction	SB					


PERSONNEL AND EQUIPMENT						
Personnel	Ellen, Bijan, Trevor, Abhinav				Site Number	34
Trailer	TDC 00162					
Equipment	Wavetronix					
SETUP DETAILS						
Coordinates	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			SITE SKETCH 
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	
			To Centerline	31.33	Feet	
Far Side			Roadway			
Type	Value	Unit	Type	Value	Unit	
RS Width	7	Inches	Edgeline to Edgeline	21.67	Feet	
RS Length	12	Inches	Edge of Pavement to Edge of Pavement	28.33	Feet	
RS Spacing	12	Inches	Rumble Strip to Rumble Strip	23.92	Feet	
Gravel Shoulder Width	1	Feet	Facility Type	2U		
RS to Edge of Pavement	2.25	Feet	Passing Allowed	No		
RS to Edge Line	1	Feet	Near Side Posted Speed Limit	55	MPH	
Edge Line to Edge of Pavement	3.16	Feet	Far Side Posted Speed Limit	55	MPH	
Cardinal Direction	W		Segment Type	Curve	Treatment	
Roadway Direction	WB					


PERSONNEL AND EQUIPMENT						
Personnel	Tim, Grant, Trevor, Abhinav				Site Number	35
Trailer	TDC 00164					
Equipment	Wavetronix and LiDAR					
SETUP DETAILS						
Coordinates	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			SITE SKETCH Control section, no rumble strips 
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	


PERSONNEL AND EQUIPMENT							
Personnel	Tim, Grant, Trevor, Abhinav					Site Number	36
Trailer	TDC 00162						
Equipment	Wavetronix						
SETUP DETAILS							
Coordinates	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			SITE SKETCH	
Type	Value	Unit	Type	Value	Unit	Control Section, no rumble strips 	
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		
			Roadway				
Type	Value	Unit	Type	Value	Unit		
RS Width	NA	Inches	Edgeline to Edgeline	21.33	Feet		
RS Length	NA	Inches	Edge of Pavement to Edge of Pavement	24.17	Feet		
RS Spacing	NA	Inches	Rumble Strip to Rumble Strip	NA	Feet		
Gravel Shoulder Width	4.75	Feet	Facility Type	2U			
RS to Edge of Pavement	NA	Feet	Passing Allowed	No			
RS to Edge Line	NA	Feet	Near Side Posted Speed Limit	55	MPH		
Edge Line to Edge of Pavement	1.83	Feet	Far Side Posted Speed Limit	55	MPH		
Cardinal Direction	S		Segment Type	Curve	Control		
Roadway Direction	WB						


PERSONNEL AND EQUIPMENT						
Personnel	Tim, Grant, Trevor, Bijan				Site Number	39
Trailer	TDC 00164					
Equipment	Wavetronix and LiDAR					
SETUP DETAILS						
Coordinates	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			SITE SKETCH 
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	
			To Centerline	31.42	Feet	
Far Side			Roadway			
Type	Value	Unit	Type	Value	Unit	
RS Width	6	Inches	Edgeline to Edgeline	23.42	Feet	
RS Length	6	Inches	Edge of Pavement to Edge of Pavement	28.33	Feet	
RS Spacing	13	Inches	Rumble Strip to Rumble Strip	23.08	Feet	
Gravel Shoulder Width	4.58	Feet	Facility Type	2U		
RS to Edge of Pavement	2	Feet	Passing Allowed	Near		
RS to Edge Line	0	Feet	Near Side Posted Speed Limit	55	MPH	
Edge Line to Edge of Pavement	2.67	Feet	Far Side Posted Speed Limit	55	MPH	
Cardinal Direction	E		Segment Type	Tangent	Treatment	
Roadway Direction	EB					


PERSONNEL AND EQUIPMENT						
Personnel	Tim, Grant, Trevor, Bijan				Site Number	40
Trailer	TDC 00162					
Equipment	Wavetronix					
SETUP DETAILS						
Coordinates	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			SITE SKETCH 
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	
			To Centerline	28.5	Feet	
Far Side			Roadway			
Type	Value	Unit	Type	Value	Unit	
RS Width	NA	Inches	Edgeline to Edgeline	21.25	Feet	
RS Length	NA	Inches	Edge of Pavement to Edge of Pavement	22.83	Feet	
RS Spacing	NA	Inches	Rumble Strip to Rumble Strip	NA	Feet	
Gravel Shoulder Width	3.25	Feet	Facility Type	2U		
RS to Edge of Pavement	NA	Feet	Passing Allowed	No		
RS to Edge Line	NA	Feet	Near Side Posted Speed Limit	55	MPH	
Edge Line to Edge of Pavement	0.83	Feet	Far Side Posted Speed Limit	55	MPH	
Cardinal Direction	W		Segment Type	Tangent	Control	
Roadway Direction	WB					


PERSONNEL AND EQUIPMENT						
Personnel	Tim, Grant, Trevor, Abhinav				Site Number	41
Trailer	TDC 00164					
Equipment	Wavetronix and LiDAR					
SETUP DETAILS						
Coordinates	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			SITE SKETCH 
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	
			To Centerline	44.83	Feet	
Far Side			Roadway			
Type	Value	Unit	Type	Value	Unit	
RS Width	8	Inches	Edgeline to Edgeline	23.42	Feet	
RS Length	7	Inches	Edge of Pavement to Edge of Pavement	29	Feet	
RS Spacing	13	Inches	Rumble Strip to Rumble Strip	23.33	Feet	
Gravel Shoulder Width	4	Feet	Facility Type	2U		
RS to Edge of Pavement	3.33	Feet	Passing Allowed	Far		
RS to Edge Line	0	Feet	Near Side Posted Speed Limit	55	MPH	
Edge Line to Edge of Pavement	2.33	Feet	Far Side Posted Speed Limit	55	MPH	
Cardinal Direction	E		Segment Type	Tangent	Treatment	
Roadway Direction	EB					


PERSONNEL AND EQUIPMENT						
Personnel	Tim, Grant, Trevor, Abhinav				Site Number	42
Trailer	TDC 00164					
Equipment	Wavetronix and LiDAR					
SETUP DETAILS						
Coordinates	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			SITE SKETCH 
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	


PERSONNEL AND EQUIPMENT						
Personnel	Tim, Grant, Abhinav				Site Number	43
Trailer	TDC 00162					
Equipment	Wavetronix					
SETUP DETAILS						
Coordinates	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			SITE SKETCH 
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	


PERSONNEL AND EQUIPMENT						
Personnel	Tim, Grant, Abhinav				Site Number	44
Trailer	TDC 00164					
Equipment	Wavetronix and LiDAR					
SETUP DETAILS						
Coordinates	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			SITE SKETCH 
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	
			Roadway			
Type	Value	Unit	Type	Value	Unit	
RS Width	10	Inches	Type	24.00	Feet	
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	


PERSONNEL AND EQUIPMENT						
Personnel	Tim, Grant, Abhinav				Site Number	45
Trailer	TDC 00164					
Equipment	Wavetronix and LiDAR					
SETUP DETAILS						
Coordinates	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			SITE SKETCH 
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	


PERSONNEL AND EQUIPMENT						
Personnel	Tim, Grant, Abhinav				Site Number	46
Trailer	TDC 00162					
Equipment	Wavetronix					
SETUP DETAILS						
Coordinates	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			Centerline			SITE SKETCH 
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	7	Feet	Pair to Pair Spacing	NA	Inches	
RS to Edge of Pavement	2.58	Feet	Trailer			
RS to Edge Line	0.08	Feet	Type	Value	Unit	
Edge Line to Edge of Pavement	2.67	Feet	To Edge of Pavement	15.42	Feet	
Cardinal Direction	E		To Edgeline	18.08	Feet	
Roadway Direction	EB		To Rumble Strip	18.00	Feet	
Far Side			To Centerline	29.67	Feet	
Type	Value	Unit	Roadway			
RS Width	8	Inches	Type	Value	Unit	
RS Length	7	Inches	Edgeline to Edgeline	23.33	Feet	
RS Spacing	13	Inches	Edge of Pavement to Edge of Pavement	28.33	Feet	
Gravel Shoulder Width	8	Feet	Rumble Strip to Rumble Strip	23.33	Feet	
RS to Edge of Pavement	2.25	Feet	Facility Type	2U		
RS to Edge Line	0.08	Feet	Passing Allowed	Far		
Edge Line to Edge of Pavement	2.33	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	


PERSONNEL AND EQUIPMENT						
Personnel	Tim, Trevor				Site Number	52
Trailer	TDC 00162					
Equipment	Wavetronix					
SETUP DETAILS						
Coordinates	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						
Personnel	Tim, Trevor				Site Number	53
Trailer	TDC 00164					
Equipment	Wavetronix					
SETUP DETAILS						
Coordinates	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			SITE SKETCH 
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	

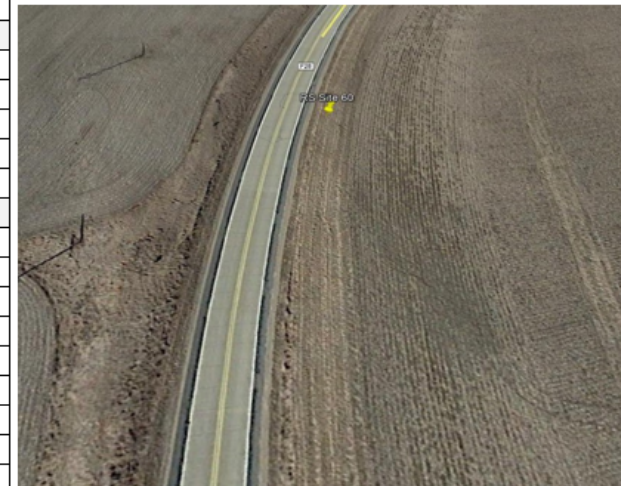
PERSONNEL AND EQUIPMENT						
Personnel	Tim, Trevor				Site Number	55
Trailer	TDC 00162					
Equipment	Wavetronix					
SETUP DETAILS						
Coordinates	42°25'58.56"N, 91°49'4.04"W					
Roadway	W35					
Nearest Town/City	Independence					
Start Time/Date	7/9/2016 16:02					
Weather	Sunny					
End Time/Date	7/10/2016 12:00					
Weather	Sunny					
MEASUREMENTS						
Near Side			Centerline			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	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	
			To Centerline	30.83	Feet	
Far Side			Roadway			
Type	Value	Unit	Type	Value	Unit	
RS Width	NA	Inches	Edgeline to Edgeline	20.83	Feet	
RS Length	NA	Inches	Edge of Pavement to Edge of Pavement	22.08	Feet	
RS Spacing	NA	Inches	Rumble Strip to Rumble Strip	NA	Feet	
Gravel Shoulder Width	5.5	Feet	Facility Type	2U		
RS to Edge of Pavement	NA	Feet	Passing Allowed	Near		
RS to Edge Line	NA	Feet	Near Side Posted Speed Limit	45	MPH	
Edge Line to Edge of Pavement	0.75	Feet	Far Side Posted Speed Limit	45	MPH	
Cardinal Direction	E		Segment Type	Curve	Treatment	
Roadway Direction	SB					

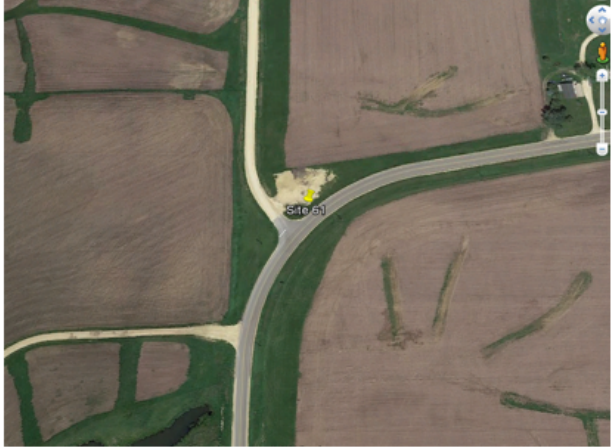
PERSONNEL AND EQUIPMENT						
Personnel	Tim, Trevor				Site Number	56
Trailer	TDC 00164					
Equipment	Wavetronix					
SETUP DETAILS						
Coordinates	42°27'39.49"N, 91°50'52.79"W					
Roadway	W35					
Nearest Town/City	Independence					
Start Time/Date	7/9/2016 16:42					
Weather	Sunny					
End Time/Date	7/11/2016 10:00					
Weather	Sunny					
MEASUREMENTS						
Near Side			Centerline			SITE SKETCH 
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	
			To Centerline	29.42	Feet	
Far Side			Roadway			
Type	Value	Unit	Type	Value	Unit	
RS Width	NA	Inches	Edgeline to Edgeline	20.67	Feet	
RS Length	NA	Inches	Edge of Pavement to Edge of Pavement	22.08	Feet	
RS Spacing	NA	Inches	Rumble Strip to Rumble Strip	NA	Feet	
Gravel Shoulder Width	4.5	Feet	Facility Type	2U		
RS to Edge of Pavement	NA	Feet	Passing Allowed	Near		
RS to Edge Line	NA	Feet	Near Side Posted Speed Limit	45	MPH	
Edge Line to Edge of Pavement	0.83	Feet	Far Side Posted Speed Limit	45	MPH	
Cardinal Direction	S		Segment Type	Tangent	Treatment	
Roadway Direction	SB					

PERSONNEL AND EQUIPMENT						
Personnel	Trevor, Tim				Site Number	57
Trailer	TDC 00162					
Equipment	Wavetronix					
SETUP DETAILS						
Coordinates	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			SITE SKETCH 
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	

PERSONNEL AND EQUIPMENT							
Personnel	Grant, Tim, Abhinav					Site Number	59
Trailer	TDC 00164						
Equipment	Wavetronix						
SETUP DETAILS							
Coordinates	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			SITE SKETCH	
Type	Value	Unit	Type	Value	Unit	Control 	
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		


PERSONNEL AND EQUIPMENT						
Personnel	Grant, Tim, Abhinav				Site Number	60
Trailer	TDC 00162					
Equipment	Wavetronix					
SETUP DETAILS						
Coordinates	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			Centerline			SITE SKETCH
Type	Value	Unit	Type	Value	Unit	
RS Width	8	Inches	RS Width	NA	Inches	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'
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	4.5	Feet	Trailer			
RS to Edge Line	0.83	Feet	Type	Value	Unit	
Edge Line to Edge of Pavement	5.25	Feet	To Edge of Pavement	16.83	Feet	
Cardinal Direction	E		To Edgeline	22	Feet	
Roadway Direction	EB		To Rumble Strip	21.25	Feet	
			To Centerline	33	Feet	
Far Side			Roadway			
Type	Value	Unit	Type	Value	Unit	
RS Width	8	Inches	Edgeline to Edgeline	22.5	Feet	
RS Length	13	Inches	Edge of Pavement to Edge of Pavement	32.25	Feet	
RS Spacing	13	Inches	Rumble Strip to Rumble Strip	24.33	Feet	
Gravel Shoulder Width	3	Feet	Facility Type	2U		
RS to Edge of Pavement	4	Feet	Passing Allowed	No		
RS to Edge Line	1	Feet	Near Side Posted Speed Limit	55	MPH	
Edge Line to Edge of Pavement	5	Feet	Far Side Posted Speed Limit	55	MPH	
Cardinal Direction	W		Segment Type	Curve	Treatment	
Roadway Direction	WB					




PERSONNEL AND EQUIPMENT						
Personnel	Grant, Trevor, Bijan				Site Number	61
Trailer	TDC 00164					
Equipment	Wavetronix					
SETUP DETAILS						
Coordinates	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			Centerline			SITE SKETCH 
Type	Value	Unit	Type	Value	Unit	
RS Width	8	Inches	RS Width	NA	Inches	
RS Length	4	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	3.5	Feet	Trailer			
RS to Edge Line	0.08	Feet	Type	Value	Unit	
Edge Line to Edge of Pavement	3.42	feet	To Edge of Pavement	14.5	Feet	
Cardinal Direction	E		To Edgeline	17.92	Feet	
Roadway Direction	NB		To Rumble Strip	18	Feet	
Far Side			To Centerline	29	Feet	
			Roadway			
Type	Value	Unit	Type	Value	Unit	
RS Width	8	Inches	Edgeline to Edgeline	22.25	Feet	
RS Length	4	Inches	Edge of Pavement to Edge of Pavement	28.83	Feet	
RS Spacing	13	Inches	Rumble Strip to Rumble Strip	21.83	Feet	
Gravel Shoulder Width	4	Feet	Facility Type	2U		
RS to Edge of Pavement	3.75	Feet	Passing Allowed	No		
RS to Edge Line	0.17	Feet	Near Side Posted Speed Limit	55	MPH	
Edge Line to Edge of Pavement	3.58	feet	Far Side Posted Speed Limit	55	MPH	
Cardinal Direction	W		Segment Type	Curve	Treatment	
Roadway Direction	SB					

PERSONNEL AND EQUIPMENT						
Personnel	Grant, Trevor, Bijan			Site Number	62	
Trailer	TDC 00162					
Equipment	Wavetronix					
SETUP DETAILS						
Coordinates	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			SITE SKETCH
Type	Value	Unit	Type	Value	Unit	
RS Width	6	Inches	RS Width	NA	Inches	No gravel shoulder, rumbles on asphalt; near side asphalt shoulder= 4'-11"; far side asphalt shoulder= 4'-9"; EOC to EOC= 24'-2"
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	
			To Centerline	29.5	Feet	
Far Side			Roadway			
Type	Value	Unit	Type	Value	Unit	
RS Width	5	Inches	Edgeline to Edgeline	21.5	Feet	
RS Length	16	Inches	Edge of Pavement to Edge of Pavement	33.92	Feet	
RS Spacing	12	Inches	Rumble Strip to Rumble Strip	25.5	Feet	
Gravel Shoulder Width	NA	Feet	Facility Type	2U		
RS to Edge of Pavement	4.25	Feet	Passing Allowed	No		
RS to Edge Line	1.83	Feet	Near Side Posted Speed Limit	55	MPH	
Edge Line to Edge of Pavement	6.08	Feet	Far Side Posted Speed Limit	55	MPH	
Cardinal Direction	W		Segment Type	Curve	Treatment	
Roadway Direction	SB					



PERSONNEL AND EQUIPMENT							
Personnel	Grant, Tim, Abhinav					Site Number	65
Trailer	TDC 00164						
Equipment	Wavetronix						
SETUP DETAILS							
Coordinates	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			SITE SKETCH	
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		

PERSONNEL AND EQUIPMENT						
Personnel	Grant, Tim, Abhinav				Site Number	66
Trailer	TDC 00162					
Equipment	Wavetronix					
SETUP DETAILS						
Coordinates	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			SITE SKETCH 
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	

APPENDIX B

PUBLIC SURVEY EXAMPLE



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.**



<p>1. Are you familiar with rumble strips? 1 = Yes 2 = No</p> <p>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</p> <p>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</p> <p>4. Do rumble strips have an impact on how fast you drive on two-lane highways? 1 = Yes 2 = No</p> <p>5. Have you ever driven over rumble strips? 1 = Yes 2 = No</p> <p>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: _____</p> <p>6. Do you feel rumble strips provide sufficient feedback (i.e., noise and vibration) to alert drivers? 1 = Yes 2 = No 3 = Not sure</p> <p>7. Do centerline rumble strips have an impact on how frequently you pass slower moving vehicles on two-lane highways? 1 = Yes 2 = No</p> <p>8. Do you live on a two-lane highway where rumble strips have been installed near your house? 1 = Yes 2 = No</p> <p>9. Do you feel rumble strips create any noise issues for nearby residents? 1 = Yes 2 = No 3 = Not sure</p> <p>10. Do you ever bike along two-lane highways where rumble strips have been installed? 1 = Yes 2 = No</p> <p>11. Do you feel rumble strips create any problems for bicyclists? 1 = Yes 2 = No 3 = Not sure</p>	<p>12. Do you ever walk or jog along two-lane highways where rumble strips have been installed? 1 = Yes 2 = No</p> <p>13. Do you feel rumble strips create any problems for pedestrians or joggers? 1 = Yes 2 = No 3 = Not sure</p> <p>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:</p> <table border="1"> <thead> <tr> <th></th> <th colspan="3">Not Effective</th> <th colspan="2">Very Effective</th> </tr> </thead> <tbody> <tr> <td>Daytime</td> <td>1</td> <td>2</td> <td>3</td> <td>4</td> <td>5</td> </tr> <tr> <td>Nighttime</td> <td>1</td> <td>2</td> <td>3</td> <td>4</td> <td>5</td> </tr> <tr> <td>Clear weather</td> <td>1</td> <td>2</td> <td>3</td> <td>4</td> <td>5</td> </tr> <tr> <td>Rain</td> <td>1</td> <td>2</td> <td>3</td> <td>4</td> <td>5</td> </tr> <tr> <td>Snow</td> <td>1</td> <td>2</td> <td>3</td> <td>4</td> <td>5</td> </tr> </tbody> </table> <p>15. Do you support the continued installation of rumble strips on two-lane highways throughout Iowa? 1 = Yes 2 = No</p> <p>16. What is your gender? 1 = Male 2 = Female</p> <p>17. What is your age? 1 = under 25 2 = 25-34 3 = 35-44 4 = 45-54 5 = 55-64 6 = 65 or above</p> <p>18. What is your home zip code? _____</p> <p>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: _____</p> <p style="text-align: center;">Thank you for your assistance!</p>		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
	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																																

APPENDIX C

PUBLIC SURVEY RESPONSES AND FREQUENCY TABLES FOR ALL SURVEY

QUESTION RESPONSES

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 ZipCode?				
ZipCode	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

Q18. What is your home ZipCode?				
ZipCode	Frequency	Percent	Cumulative Frequency	Cumulative Percent
50046	4	0.27	148	10.02
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

Q18. What is your home ZipCode?				
ZipCode	Frequency	Percent	Cumulative Frequency	Cumulative Percent
50237	1	0.07	216	14.62
50248	3	0.20	219	14.83
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

Q18. What is your home ZipCode?				
ZipCode	Frequency	Percent	Cumulative Frequency	Cumulative Percent
50423	1	0.07	456	30.87
50425	1	0.07	457	30.94
50428	15	1.02	472	31.96
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

Q18. What is your home ZipCode?				
ZipCode	Frequency	Percent	Cumulative Frequency	Cumulative Percent
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
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

Q18. What is your home ZipCode?				
ZipCode	Frequency	Percent	Cumulative Frequency	Cumulative Percent
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
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

Q18. What is your home ZipCode?				
ZipCode	Frequency	Percent	Cumulative Frequency	Cumulative Percent
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
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

Q18. What is your home ZipCode?				
ZipCode	Frequency	Percent	Cumulative Frequency	Cumulative Percent
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
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

Q18. What is your home ZipCode?				
ZipCode	Frequency	Percent	Cumulative Frequency	Cumulative Percent
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
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

Q18. What is your home ZipCode?				
ZipCode	Frequency	Percent	Cumulative Frequency	Cumulative Percent
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
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

APPENDIX D

PUBLIC DATA COLLECTION PERMISSION LETTER

IOWA STATE UNIVERSITY
OF SCIENCE AND TECHNOLOGY

College of Engineering
Department of Civil, Construction
and Environmental Engineering
Ames, Iowa 50011-3232
Phone 515 294-3381
FAX 515 294-8216

June 14, 2016

To Whom It May Concern:

The Iowa State University (ISU) Institute for Transportation (InTrans) is currently conducting a research project under a contract with the Iowa Department of Transportation (DOT) and the Iowa Highway Research Board (IHRB). This project will lead to the development of guidelines to assist state and county road agencies in deploying centerline and shoulder rumble strips across the state of Iowa.

As a part of this project, research staff will be setting up a field trailer that will be used to collect information on vehicle positioning across various road segments with various lane and shoulder widths, including select locations where rumble strips have been installed. The results of these field studies will, in part, assist in determining locations where rumble strips are likely to have the greatest benefit in terms of reducing traffic crashes, injuries, and fatalities. If you have any questions or require further information regarding these studies, please feel free to contact me directly at (515) 294-3381, (248) 953-6609, or pts@iastate.edu.

Sincerely,

Peter T. Savolainen, Ph.D., P.E.
Associate Professor
Civil, Construction and Environmental Engineering
Iowa State University
482A Town Engineering Bldg
Ames, IA 50011
(515) 294-3381
pts@iastate.edu