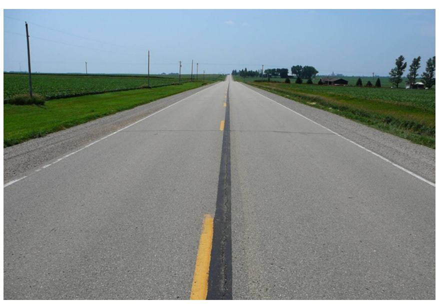
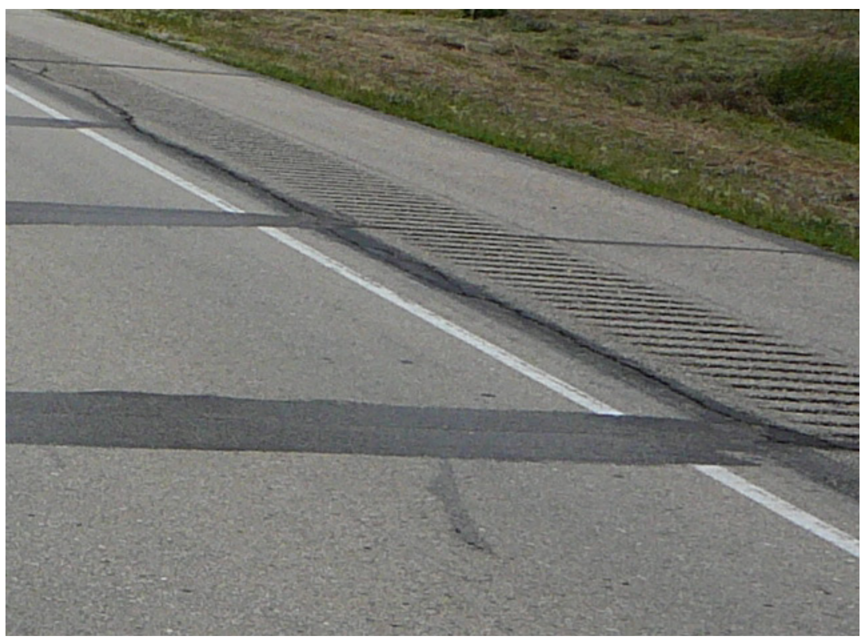
Safety Benefits of Paved Shoulders

MTC
MIDWEST TRANSPORTATION CONSORTIUM

Updated Final Report
August 2010





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16. Abstract

Single vehicle run-off-road (SVROR) crashes are the largest type of fatal passenger vehicle crash in the US (NCHRP 500 2003). In Iowa, ROR crashes accounted for 36% of rural crashes and 9% of total crashes in 2006. Run-off-road crashes accounted for more than 61.8% of rural fatal crashes and 32.6% of total fatal crashes in Iowa in 2006.

The research described in this report evaluates the effectiveness of paved shoulders. Generalized linear models were used to investigate the relationship between crash reduction and implementation of paved shoulders. The response variable was quarterly crash frequency. Separate models were developed for cross-centerline crashes, run-off-road crashes, and single vehicle run-off-road crashes. The model for each independent variable considered over-dispersion and excess zeroes. The best fit model for total crashes per quarter was a zero inflated negative binomial model. Model results indicated that the total amount of right shoulder, presence of a median, speed limit, addition of a paved shoulder and years after addition of a paved shoulder were statistically significant. The effect of paved shoulder varied over time depending on the years after treatment. At 10 years, the decrease is total crashes due to paved shoulders was 15.9%. A negative binominal model was the best fit model for cross-centerline crashes and the model indicated that effect of paved shoulders was not statistically significant. ROR crashes were modeled assuming the distribution of the response variable is a mixture of Poisson and zeros (ZIP). The amount of total right shoulder available, presence of a divided median, speed limit and years after paved shoulders were installed were all statistically significant. The effect of paved shoulder on run-off-road crashes by quarter varied over time depending on the years after treatment. At 10 years, sites with paved shoulders have 13.5% fewer ROR crashes than control sites. Single vehicle run-off-road crashes were modeled assuming the distribution of the response variable is a mixture of Poisson and zeros. The total amount of right shoulder available, presence of a divided median, speed limit and years after paved shoulders were installed were all statistically significant. The effect of paved shoulder on single vehicle run-off-road crashes by quarter varied over time depending on the years after treatment. At 10 years, SVROR crashes are 16.4% lower for sections with paved shoulders than for sites with no treatment.

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SAFETY BENEFITS OF PAVED SHOULDERS

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

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EXECUTIVE SUMMARY

Single vehicle run-off-road (SVROR) crashes are the most common type of fatal passenger vehicle crash in the United States (NCHRP 500 2003). In Iowa, ROR crashes accounted for 36% of all rural crashes, more than 61.8% of rural fatal crashes, 9% of total crashes, and 32.6% of total fatal crashes in 2006.

Paved shoulders are a potential countermeasure for ROR crashes. Several studies are available that have generally indicated that paved shoulders are effective in reducing crashes. However, the number of studies that quantify the benefits is limited.

In 2004, Iowa adopted a paved shoulder policy for higher volume roads, but a wide range of paved shoulder types has been utilized for many years in the state. Because the benefits of paved shoulders have not been quantified, the Iowa Department of Transportation (Iowa DOT) requested a study to analyze the safety performance of various paved shoulder designs on a wide spectrum of traffic and roadway types.

The research described in this report was designed to evaluate the effectiveness of paved shoulders. As part of the research, two surveys were conducted that assessed the opinions of field maintenance personnel and law enforcement personnel regarding the effectiveness of paved shoulders. Most maintenance personnel felt that paved shoulders lead to reduced maintenance costs, and most law enforcement personnel felt that paved shoulders reduce ROR crashes and improve safety for officers who have to pull over for traffic stops.

This research also included a crash analysis for non-Interstate roadways where paved shoulders have been installed in Iowa. The team made site visits and collected roadway data for 256 roadway sections in Iowa. The majority included locations where paved shoulders had been installed, but a number of control sections were collected as well. Each test segment was reviewed, and the construction year in which paved shoulders were implemented was determined. In some cases, the roadway segment could not be located in a geographic information management systems (GIMS) database, and in other cases the construction year could not be determined. These cases were removed from further analysis. This resulted in a total of 220 sites analyzed, including 77 control sections and 143 test sections. Sections included both two- and four-lane roadways. Four-lane roadways were both divided and undivided.

Generalized linear models were used to investigate the relationship between crash reduction and implementation of paved shoulders. The response variable was quarterly crash frequency. Traffic volume was modeled as offsets. Separate models were developed for cross-centerline (CL) crashes, run-off-road (ROR) crashes which included all road departure crashes, and single vehicle run-off-road (SVROR) crashes which included only road departures involving a single vehicle. The model for each independent variable considered over-dispersion and excess zeroes.

The best fit model for total crashes per quarter was a zero inflated negative binomial model. Model results indicated that the total amount of right shoulder, presence of a median, speed limit, addition of a paved shoulder and years after addition of a paved shoulder were statistically significant. The effect of paved shoulder varied over time depending on the years after treatment. At 10 years, the decrease is total crashes due to paved shoulders was 15.9%.

A negative binominal model was the best fit model for cross-centerline crashes and the model indicated that effect of paved shoulders was not statistically significant.

ROR crashes were modeled assuming the distribution of the response variable is a mixture of Poisson and zeros. The amount of total right shoulder available, presence of a divided median, speed limit and years after paved shoulders were installed were all statistically significant. The effect of paved shoulder on run-off-road crashes by quarter varied over time depending on the years after treatment. At 10 years, sites with paved shoulders have 13.5% fewer ROR crashes than control sites.

Single vehicle run-off-road crashes were modeled assuming the distribution of the response variable is a mixture of Poisson and zeros. The total amount of right shoulder available, presence of a divided median, speed limit and years after paved shoulders were installed were all statistically significant. The effect of paved shoulder on single vehicle run-off-road crashes by quarter varied over time depending on the years after treatment. At 10 years, SVROR crashes are 16.4% lower for sections with paved shoulders than for sites with no treatment.

The report is organized in the following way:

- Chapter 1 summarizes a literature review of the effectiveness of paved shoulders and rumble strips.
- Chapter 2 describes the project scope and summarizes Iowa DOT paved shoulder practices.
- Chapter 3 provides the results of a survey of field maintenance personnel and law enforcement personnel regarding their experience with paved shoulders.
- Chapter 4 describes data collection.
- Chapter 5 describes the analysis of the data.

1. INTRODUCTION

Single vehicle run-off-road (SVROR) crashes are the single most common type of fatal passenger vehicle crash in the United States (NCHRP 500 2003). A ROR crash is defined as a crash in which one or more vehicles has at least one of the vehicle's first three sequences of events coded as ROR-right, ROR-left, or ROR-straight. Many ROR crashes are rural crashes, which are defined as crashes that occur one or more miles outside of an incorporated area. In Iowa, rural crashes accounted for 13,255 out of 54,785 crashes in 2006 (24.2%). An extraction of rural ROR crashes that occurred in 2006 from the Iowa Department of Transportation (DOT) crash database indicated that ROR crashes accounted for 35.5% of rural crashes and 8.6% of total crashes. Moreover, ROR crashes accounted for more than 61.8% of rural fatal crashes and 32.6% of total fatal crashes in Iowa in 2006.

Paved shoulders are a potential countermeasure for ROR crashes. Shoulder rumble strips are also potentially effective in reducing ROR crashes.

1.1 Paved Shoulders

It is generally accepted that shoulders play an important role in highway design. They provide additional recovery space for errant vehicles and lateral support for the pavement structure.

Regarding lateral support, Benekohal (1990) stated that, as a rule of thumb, loads applied within 6 in. of the concrete slab edge will produce significant stresses at the slab edge. Benekohal also concluded that, on roads widened beyond the conventional 12 ft, painted lane lines have a greater influence on truck wheel placement than the slab edge. The author also found that providing an additional 18 to 22 in. of pavement beyond the lane line can prevent tractor-semitrailers from passing within 6 in. of the slab edge.

1.1.1 Safety Benefits

Heimbach (1974) found that rural two-lane highways with paved shoulders had a significantly lower crash rate than highways with unstabilized shoulders. The National Cooperative Highway Research Program (NCHRP) Report 197, published in 1978, also found that paved shoulders exhibit safety benefits. The report concluded that roads with paved shoulders have lower crash rates than roads with unpaved shoulders of the same width. It also concluded that shoulder widths and whether shoulders were paved or unpaved had a greater effect on crash rates than lane widths. A linear model was developed to predict crash rates for roadways with varying lane and paved shoulder widths. The model was generally able to represent predicted relationships, but there were some inconsistencies. In general, crash rates decreased as shoulder widths increased. This rule applies for sections of roadway with 3° or less of horizontal curvature. However, the opposite result was true for roadways with an average daily traffic (ADT) of less than 1,000 vehicles per day (VPD) or greater than 5,000 VPD (NCHRP 197 1974).

Zegeer (1981) conducted a comparative analysis study of state primary, state secondary, and rural two-lane roads in Kentucky. The sections were selected so that they did not include any major intersections. A database of 15,944 miles of road was compiled from computer tape, and eight classifications of roads based on ADT were used. Due to about 70% of the total sample having no shoulder, shoulders were defined as paved or densely graded. Grass and soil were not considered shoulders because they are not suitable for driving. Zegeer found that ROR, head-on, and opposite direction sideswipe crash rates decreased as shoulder width increased from 0 to 9 ft, but the crash rates increased slightly for shoulders of 10 to 12 ft. Crash severity, however, did not decrease with wider shoulders. For roadways with lane widths greater than 10 ft, Zegeer determined that it was economically beneficial to widen the shoulders if there are at least five ROR and/or opposite direction crashes in one year. For roads without shoulders, the optimal shoulder width to install was estimated to be 5 ft (Zegeer 1981).

Not all studies have concluded that paved shoulders offer a significant benefit, however. Abboud (2001) evaluated 2 ft and 4 ft paved shoulders on two-lane highways in Alabama and analyzed them against county statistics for the expected number of crashes on the treated segments. Crash records were not kept on specific routes with similar characteristics, and therefore total county crashes in the before and after period were used as a control. Crash frequency by type and crash severity were analyzed, but no statistically significant differences were found at the 0.05 alpha confidence level (Abboud 2001).

Similarly, a study conducted by Souleyrette (2001) did not demonstrate significant crash reduction benefits. Souleyrette's study focused specifically on rural two-lane and rural four-lane divided non-Interstate freeways in the state of Iowa. Only targeted crashes were considered for this study; intersection crashes, median crashes, and roadway crashes were excluded because they were assumed to be non-shoulder related. Limited data availability due to conservative shoulder construction practices in Iowa prevented statistical significance from being obtained with any of the results. Trends of reduced crash rates were noted but could not be verified with confidence. The report was able to determine, however, that a reduction of up to $366 per mile per year can be realized by paving shoulders on two-lane roads.

1.1.2 Bicycle Accommodation

Bicyclist safety and comfort is another benefit of paved shoulders. In 1997, Harkey found that paved shoulders and bicycle lanes act essentially the same in terms of operations. By studying the separation distance between motorists and bicyclists on varying shoulder widths, Harkey also found that bicycle lane widths (paved shoulder widths) as narrow as three ft can allow safe interactions between motorists and bicyclists. Encroachments by motorists into adjacent lanes when passing bicyclists were also studied, but there were few observed encroachments and the encroachments were not attributable to shoulder width. Harkey's findings, however, only apply to roadways similar to the ones in the study. These include roadways with vehicle speeds at or below 50 mph, lane widths of at least 11 ft, and minimal horizontal and vertical sight restrictions. Roadways with significant curvature or significant large truck traffic may require wider bicycle lanes (Harkey 1997).

The Federal Highway Administration (FHWA) has developed the bicycle compatibility index (BCI), a level of service concept for bicyclists. According to the BCI Implementation Manual, the presence or absence of a bicycle lane or paved shoulder has the greatest effect of any variable on the comfort level of bicyclists. On the one hand, a bicycle lane or a paved shoulder of at least 0.9 m (approximately 3 ft) can increase the level of service for that segment by an entire letter grade on an “A” through ”F” scale. On the other hand, higher volumes and higher speeds result in a slight decrease in level of service. The decrease, however, is much smaller than the increase resulting from a 3 ft paved shoulder (Bicycle Compatibility Index 1999).

1.1.3 Operational Benefits

The operational benefits of paved shoulders were not the focus of the present study, but they are worth mentioning as an additional benefit of paving shoulders. Turner et al. (1982) have reported findings about roadway operations based on a study conducted on two-lane roadways without shoulders, two-lane roadways with full (at least 6 ft) paved shoulders, and four-lane undivided roadways without paved shoulders. The study focused on three key elements of operations: vehicle speed, platooning, and shoulder use.

On two-lane roads without paved shoulders, vehicle speeds dropped dramatically as volume increased. A similar trend was observed on two-lane roads with shoulders, except the trend diminished at around 150 vehicles per hour. Beyond this point, vehicle speeds did not decrease with an increase in volume. The difference in trends became significant at about 200 vehicles per hour. At volumes above 200 vehicles per hour, the average vehicle speed was about 10% higher on two-lane highways with paved shoulders than on those without (Turner 1982).

The amount of vehicle platooning experienced on a roadway increased with increased volumes, but appeared to level out at approximately 200 vehicles per hour on two-lane roads with paved shoulders. Vehicle platooning on two-lane roads without shoulders appeared to continue to increase exponentially beyond the 200 vehicles per hour mark. This observation led to the interpolated conclusion that, at volumes above 200 vehicles per hour, two-lane roads with paved shoulders would experience a smaller percentage of vehicles driving in platoons than would two-lane roads without paved shoulders (Turner 1982).

1.2 Rumble Strips

Paved shoulders allow additional recovery room for errant vehicles, but they do not alert distracted drivers who are no longer driving in their intended lane. Rumble strips provide an audible and tactile alert to drivers who have become distracted and drift away from their travel lane. In evaluating the impact of rumble strips, some research reports have attempted to differentiate between ROR crashes and drift-off-road (DOR) crashes. The difference between the two types is that a ROR crash may result from a driver swerving to avoid some other danger in the roadway. In this case, rumble strips would be ineffective. A DOR crash occurs when a driver has fallen asleep or has become distracted in some other manner, such as by looking at a map. In this case, rumble strips can alert the driver of the impending danger, and the driver can take the appropriate action. In a study conducted by Morena (2003), DOR crashes account for 40% to

71% of all ROR crashes on rural roads in Michigan, with ADT values ranging from 5,000 to 11,000 VPD.

1.2.1 Safety Benefits of Shoulder Rumble Strips

Installing shoulder rumble strips on the Interstate system has proven to be effective in reducing ROR crashes, but these results may not directly translate to rural two-lane roads. Neuman (2003) speculates that rumble strips may be less effective on a two-lane road because there a vehicle has a much smaller recovery area once it has been alerted. However, he also suggests that rumble strips may be more effective on two-lane rural roads than on Interstate roads because two-lane roads have a smaller recovery area and a less forgiving roadside. Thus, allowing the driver time to recover before leaving the road entirely could have a much more significant safety impact on two-lane roads than on an Interstate. The alignment of two-lane highways is also generally less forgiving than that of the Interstate, creating a greater need for a warning device to keep drivers on the roadway. Because no studies are currently available pertaining specifically to the safety benefits of rumble strips on two-lane rural roads, Neuman estimated that a 20% to 30% reduction in ROR crashes after the installation of shoulder rumble strips is realistic based on rural freeway experience.

The New York State Department of Transportation (NYSDOT) began installing continuous shoulder rumble strips on many of its roads in 1993. The NYSDOT began this process by including continuous shoulder rumble strips with its regular construction and as site-specific projects on existing roadways. The New York State Thruway Authority (NYSTA), which owns and operates private toll roads, also installed continuous shoulder rumble strips between 1992 and 1996. The advantage of the NYSTA data is uniformity, because the data are recorded by a dedicated troop of the state police force and there are a limited number of miles from which to collect data. Both New York agencies had a limited amount of before and after data, so statistical significance was not tested, but both agencies found a crash reduction of 65% to 70%. It should be noted, however, that some observations were made during years that included construction of a "[non] significant percentage" of continuous shoulder rumble strips (Perrillo 1998).

Rumble strips were similarly installed on 80% of the Pennsylvania Turnpike between 1989 and 1994. Early results after the first five installation projects were completed found a 70% reduction in DOR crashes. After speculation of regression to the mean and other factors affecting the results, a follow-up study was conducted. The study included all reportable accidents from 1990 to 1995 and found a slightly more modest result of a 60% reduction in DOR crashes (Hickey 1997). These results, however, were not tested for statistical significance.

In another approach, Hanley et al. (2000) evaluated four accident reduction factors currently used by the California Department of Transportation (CALTRANS), including rumble strip installation, defined as any construction for which a laterally positioned rumble strip had been installed. In most cases, the study indicated that some shoulder widening occurred as well. The researchers found statistically significant accident reduction factors for rumble strip installations.

Garder and Davies evaluated the effectiveness of continuous shoulder rumble strips on reducing crashes on rural Interstates in Maine. The authors found that the presence of these installations reduced crashes overall by 27%, sleep-related ROR crashes by about 58%, and dry road ROR crashes by about 43%. They also found that fatal crashes were reduced more than other crashes.

Smith and Ivan (2005) evaluated the amount of crash reduction due to milled-in shoulder rumble strips on limited-access highways. The authors used a three-year before installation and three-year after installation period on sections of 20 freeways, including some sections without rumble strips. They found that shoulder rumble strips overall reduced single-vehicle, fixed-object crashes by 33%. The results also indicated that crashes were reduced by as much as 48.5% within interchange areas and as little as 12.8% on sections where the speed limit was less than 65 mph. The authors also found that crashes increased in areas where rumble strips were not installed.

1.2.2 Safety Benefits of Edge line Rumble Strips

Edge line rumble strips (ERSs) are rumble strips that are milled-in at the painted edge line, as shown in Figure 1.1. They are different from regular shoulder rumble strips because typical shoulder rumble strips are installed several inches outside of the edge line. However, ERSs still require the presence of a shoulder because they are two to three times wider than the lane line itself. There are several potential benefits of ERSs. They can increase painted edgeline visibility and longevity, provide additional recovery room for errant vehicles, and provide more room for bicyclists on the shoulder.

Figure 1.1. Edge line rumble strip

Edge line rumble strips provide increased visibility and longevity of the painted edge line based on three factors. First, the painted edge line is more visible at night and in the rain because the paint is on a vertical surface off of which headlights reflect, as shown in Figure 1.2. Second, the painted edge line comes into less contact with tires, because there will be less encroachment onto the edge line and drivers are discouraged from positioning their tires on the edge line for extended periods of time due to the noise and vibrations generated by the rumble strips. Finally, there is less surface area contact with the tires because the edgeline is partially milled into the roadway, preventing full, direct contact with tires (Miles 2005).

Figure 1.2. Nighttime view of edgeline rumble strip (image source: http://www.tfhrc.gov/pubrds/06jul/images/morena14.jpg)

Texas conducted a preliminary study to determine the extent of the benefits received by ERSs. The study was conducted on a two-lane road in Texas with an 11 ft travel lane in each direction separated by a 4 ft wide center segment marked with centerline pavement markings. Before and after data were collected along this five-mile segment of road between September 10 and September 22, 2004 and November 5 and November 17, 2004, respectively (Miles 2005).

A study by Miles (2005) used rumble strips that were 12 in. wide, 4 in. on marked edge line and 8 in. on shoulder pavement. Pneumatic road tubes were used to collect volume, speed, and lateral position data. Video footage was also collected in order to classify the shoulder encroachment maneuvers and determine if the ERSs caused any erratic maneuvers by drivers. A total of 2,985 shoulder encroachments were observed during the 13 days of before and 13 days of after installation footage. No erratic maneuvers were observed in the video data. Statistical t-tests were performed on the data to determine significance at the 95% confidence level for any changes in driver behavior (Miles 2005).

The data revealed an overall reduction in shoulder encroachments of 46.7%. When broken down by encroachment type, the "other" case experienced the greatest proportional decrease in shoulder encroachments. The "other" case included "inadvertent contact with the edge line because of natural lane shifting, driver inattention or fatigue, swaying motions of trailers, or large load width." Encroachments classified as "other" are categorized as one of four types, ranging from "right tires hit," for when only the right tires contact the rumble strips, to "around," for when both sets of tires completely cross over the rumble strips (Miles 2005).

While the number of encroachments decreased, lateral position of vehicles increased in distance beyond the edge line. This was not statistically significant, however, and standard deviations were large. The general increase in encroachment distance was attributed to the fact that the treatment was most effective in limiting "other" encroachments that involve only the vehicles' right tires contacting the rumble strips. Certain maneuvers, such as straddling maneuvers by vehicles with three or more axles, actually increased. This is likely because it is difficult to keep wide loads and swaying trailers in the travel lane, so a conscious decision may have been made by these drivers to straddle the ERSs. "Passing" drivers in two-axle vehicles were also more likely to pull completely onto the shoulder when allowing faster vehicles to pass in order to avoid the annoyance of their left tire driving along the ERSs (Miles 2005). These observations may create more wear and tear on shoulders not designed for vehicle traffic and may add to bicyclist discomfort, but these are not necessarily viewed as less safe for drivers using the facility.

In another study, Corkle et al. (2001) summarized eight research studies on edge line rumble strips and found that ROR crashes were reduced by 20% to 72%.

1.2.3 Bicycle Accommodation with Shoulder Rumble Strips

Bicyclists have the right to ride in the right-hand lane on Iowa highways, excluding the Interstate highway system and where explicitly prohibited; therefore, highways should be designed to accommodate them (2007 Iowa Code §321.324). In addition to their legal right to access the right-most travel lane from the shoulder, bicyclists may need to access the travel lanes in order to avoid debris on the shoulder. A bicyclist may also need to access the travel lane when approaching a right-turn lane to avoid any potential collisions with a turning vehicle. Rumble strips present a problem in this regard because they are designed to vibrate cars and alert inattentive drivers. This is a safety feature for motor vehicles, but it is a dangerous obstacle for bicyclists (Moeur 2000).

In Arizona, most of the bicycles operated on the streets and highways do not have any suspension or shock absorbers. The only shock absorption these bicycles have is in their tires, saddles, hand grips, and the riders themselves. This means the vertical displacement created by the rumble strips will have a more severe effect on bicycles than on cars, trucks, or motorcycles. A gap pattern in rumble strips was developed in order to reach a compromise between motorist and bicyclist safety (Moeur 2000).

In their guide for development of bicycle facilities, the American Association of State Highway and Transportation Officials (AASHTO) recommends a minimum design speed of 20 mph in general, whether rumble strips are present or not, and 30 mph where down grades exceeding 4% or strong winds are present (AASHTO 1999). In testing gap lengths in rumble strips, bicyclists attempted to navigate the gaps in a gap pattern with an average of 25 mph, but speeds ranged up to 31 mph. All skill levels of bicyclists were able to navigate both a 10 and 12 ft gap, but the bicyclists felt that the 10 ft gap would be "too tight" for "real world" applications (Moeur 2000).

A 12 ft gap pattern allows for a vehicle to leave the roadway with up to a 4.7° departure angle and still have the full right tire hit a 12 in. wide rumble strip. Moeur (2000) found a study stating that the typical departure angle for a ROR crash is 3°, but other research contradicts this finding. A 1986 study found only 17% of rural arterial ROR crash impacts occur at 5° or less (Mak 1986). While the impact angle may be different than the departure angle, it is reasonable to assume that they would be approximately similar. It may also be appropriate to assume vehicles leaving the roadway at higher angles are doing so to avoid another vehicle or because of ice or edge drop-off, not necessarily because of fatigue or distraction.

Establishing a regular pattern for the rumble strip gaps will allow bicyclists to easily find a gap when necessary. For the 12 ft gap pattern, a 40 ft and 60 ft cycle were considered acceptable. The 40 ft cycle would consist of 28 ft of rumble strips followed by a 12 ft gap, and so on. The 60 ft cycle would likewise consist of 48 ft of rumble strips followed by a 12 ft gap, and so on. The 40 ft cycle allows for 70% coverage of rumble strips and the 60 ft pattern provides 80% coverage. Both patterns provide a sufficient frequency of gaps for bicyclists to depart the shoulder in advance of hazards and intersections (Moeur 2000).

2. DESCRIPTION OF PROJECT

2.1 Project Scope

The value of paved shoulders has been acknowledged for many years by transportation agencies and road users alike. Improved safety and convenience as well as reduced routine maintenance costs are all common benefits attributed to paved shoulders. In 2004, Iowa adopted a paved shoulder policy for higher volume roads, but a broad diversity of paved shoulder types has been utilized for many years in the state. Since the benefits of paved shoulders have not been quantified, the Iowa DOT requested a study to analyze the safety performance of various paved shoulder designs on a wide spectrum of traffic and roadway types.

Although several types and designs of paved shoulders have been constructed by contract and installed by agency maintenance staff for many years, an extensive analytical analysis of safety benefits has not been undertaken. Many design and maintenance decisions regarding paved shoulders must rely on subjective data and intuitive judgment. As a result, there is a need to quantify the safety impacts of paved shoulders so that agencies can make better decisions on the costs and benefits of improvements.

In order to address this need, this research evaluated the effectiveness of paved shoulders in reducing the number of crashes. This study evaluated all non-Interstate roadway types in Iowa where paved shoulders have been installed. The study collected data over a large number of segments where paved shoulders have been installed and along control sections. A crash analysis was conducted as described in Sections 3 and 4. A survey was also conducted to assess the opinion of field maintenance personnel and law enforcement personnel as to their experience with paved shoulders.

2.2 Iowa Department of Transportation Current Practices

The Iowa DOT Design Manual suggests that 4 ft paved shoulders be included in all National Highway System (NHS) projects. Non-NHS projects should also include paved shoulders if the current year ADT is 3,000 or more. The manual's suggestions are as follows:

> For non-NHS highways with a current year ADT of less than 3,000, a combination of other factors such as those listed below needs to be considered to determine if paved shoulders are appropriate:
>
> - Design year ADT: even if current year ADT doesn't warrant paved shoulders, design year ADT may be high enough that the designer should consider paved shoulders.
> - Run-off-the-road crash rate: paved shoulders should be considered for segments of roadway that exhibit a high run-off-the-road crash rate.
> - Horizontal and vertical alignment: paved shoulders should be considered for segments of roadway with a high number of horizontal curves—paved shoulders can reduce problems associated with off-tracking. Segments of road with steep

grades should also receive consideration for paved shoulders, as storm runoff can cause erosion of shoulder rock on steep grades.

- High truck volumes: segments of roadway that carry high truck volumes may be candidates for paved shoulders.
- Maintenance issues: paved shoulders should also be considered for segments of roadway that experience continuing problems with edge rut.
- Shoulder width continuity: continuity of paved shoulder width is desirable along segments of a corridor.
- Rumble strips: rumble strips are normally not placed on paved shoulders less than 4 ft wide.
- Multiple widening units: consider how many times the pavement has been or may be widened. Multiple narrow widening units are undesirable—they can create an uneven surface and lead to additional maintenance. Paved shoulders may be more appropriate.
- Cost differential: the cost for 4 ft paved shoulders is only slightly more than for pavement widening. The safety benefits of paved shoulders may outweigh the extra cost.
- Bicycle accommodation: if bicycle accommodation is warranted, minimum 4 ft shoulders are recommended. (Design Manual)

Wider shoulders may be appropriate if paved shoulders are warranted for bicycle accommodation. The Office of Systems Planning should be consulted for guidance in this decision. For example, if a state highway is within a statewide trail corridor, 6 ft paved shoulders may be recommended (Design Manual).

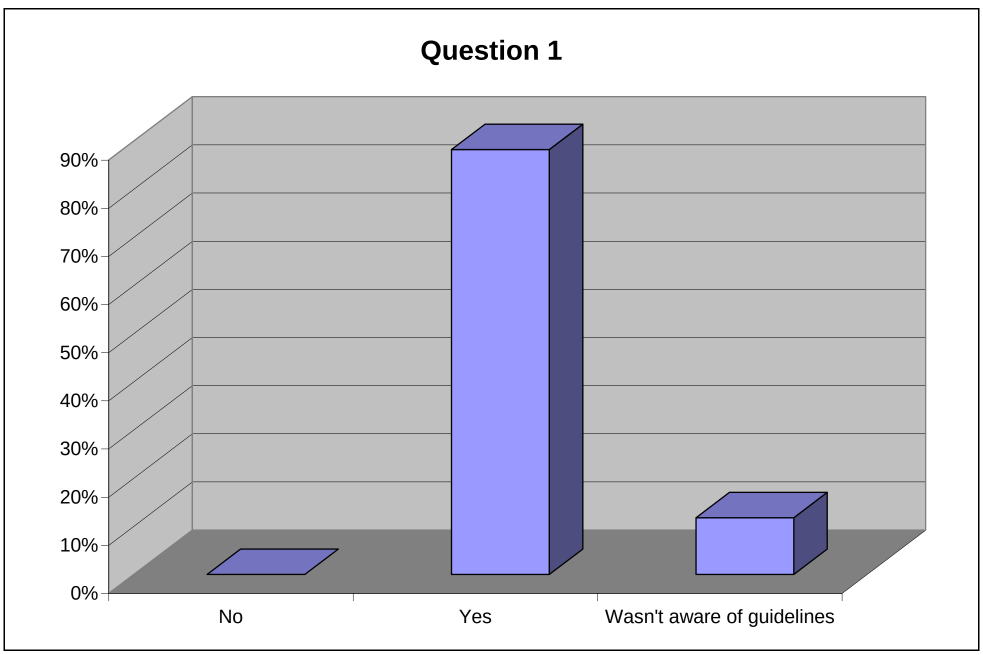
3. SURVEY OF EXPERT OPINION FIELD MAINTENANCE AND LAW ENFORCEMENT

A survey was conducted to assess the opinion of field maintenance personnel and law enforcement personnel and to obtain expert opinion about the effectiveness of paved shoulders. Another survey was sent to law enforcement personnel to assess their subjective opinions about how effective paved shoulders are in reducing crashes. The results of both surveys are provided in the following sections.

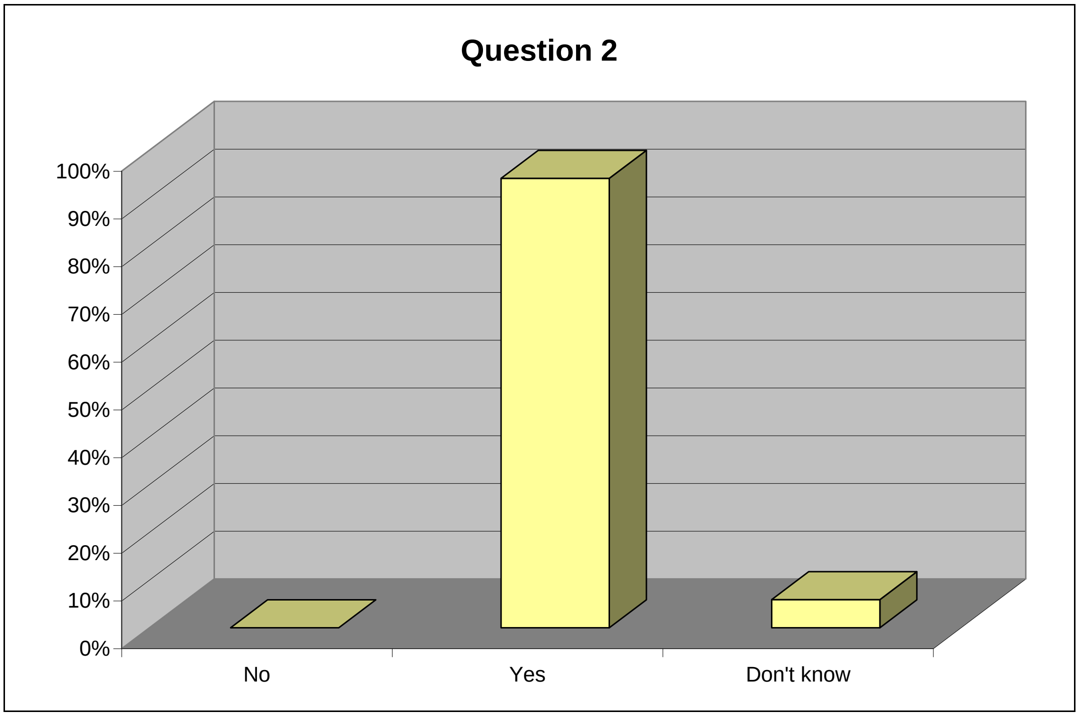
3.1 Survey of Field Maintenance Personnel

A survey about the effectiveness of paved shoulders related to maintenance was sent to all six Iowa DOT districts. It was beyond the scope of this project to evaluate the improvement in pavement performance due to the adding of paved shoulders. However, the survey provides a subjective measure of how paved shoulders might improve maintenance based on the expert opinions of maintenance personnel. Seventeen people from the six districts responded to the following questions. Responses to the questions are also shown.

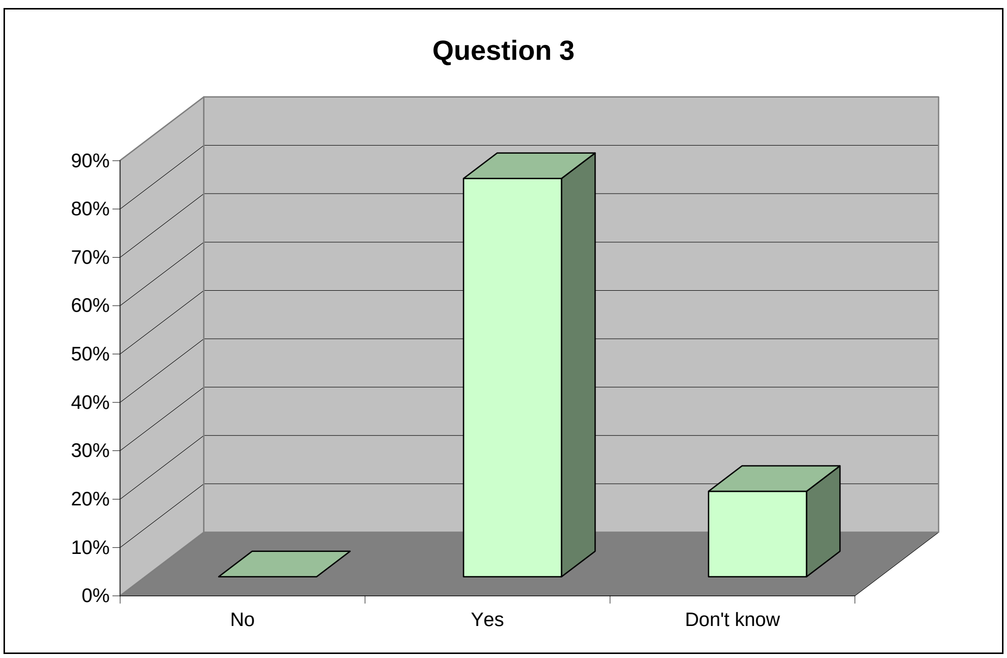
(1) Approximately three years ago, the Iowa DOT adopted paved shoulder guidelines for new and rehabilitated roads in Iowa. Do you approve of these guidelines?



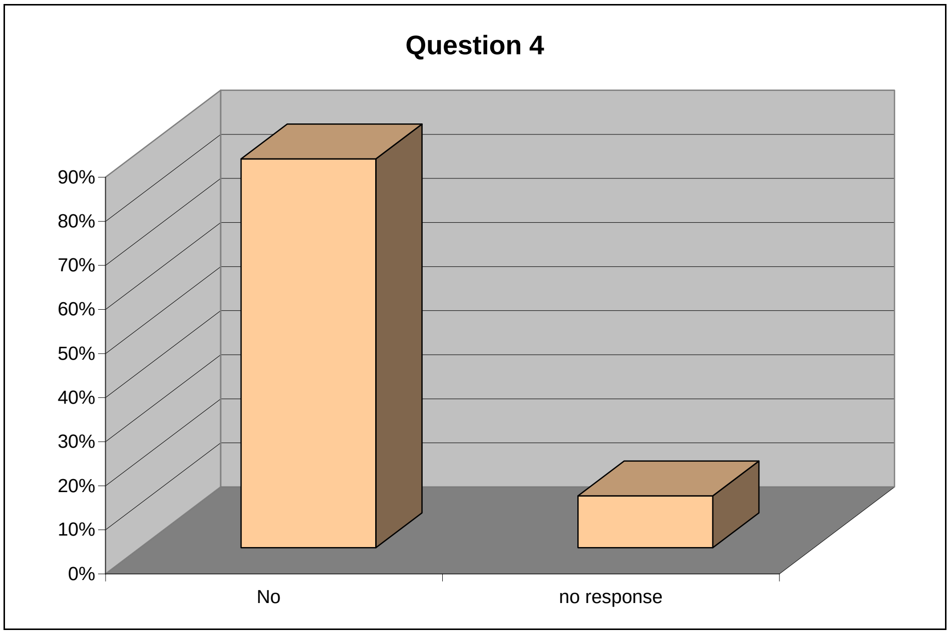
(2) Do you think paved shoulders reduce the hours required to maintain shoulders and perform edge rut repair, allowing more time to be spent on other priority activities?



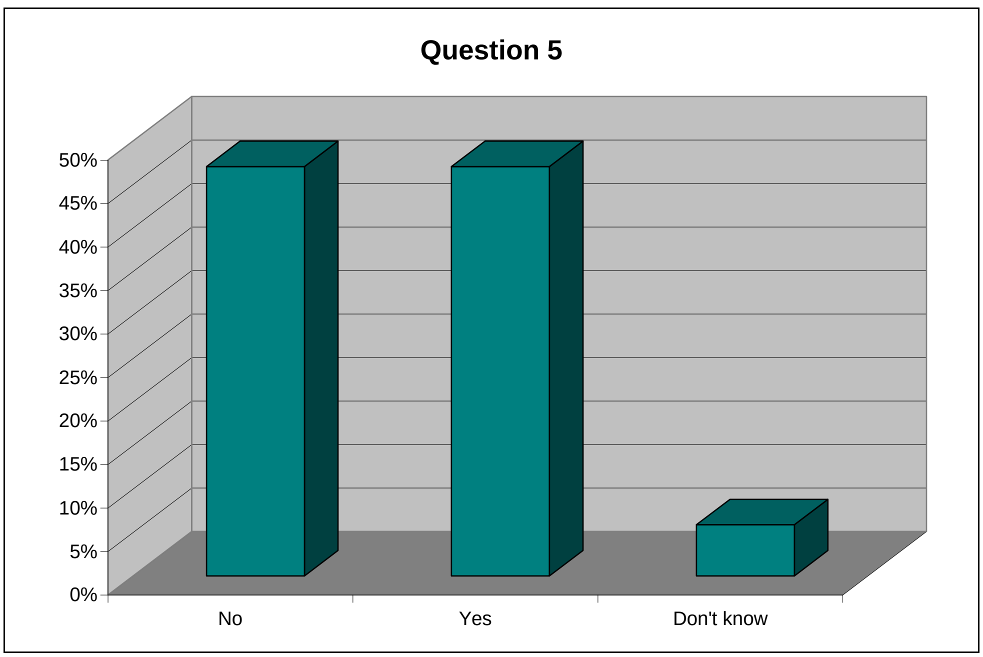
(3) Do you think paved shoulders reduce the cost of shoulder maintenance?



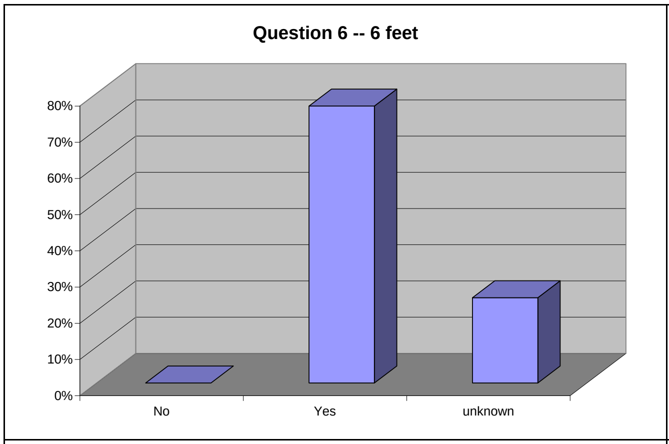
(4) If you answered yes to #3, do you have any documentation or records of reduced costs?

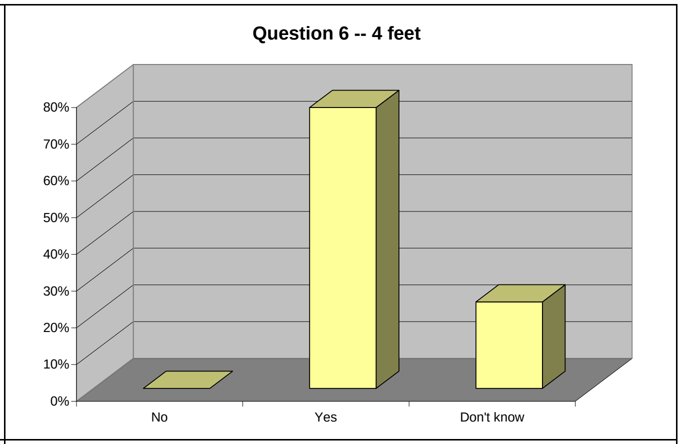


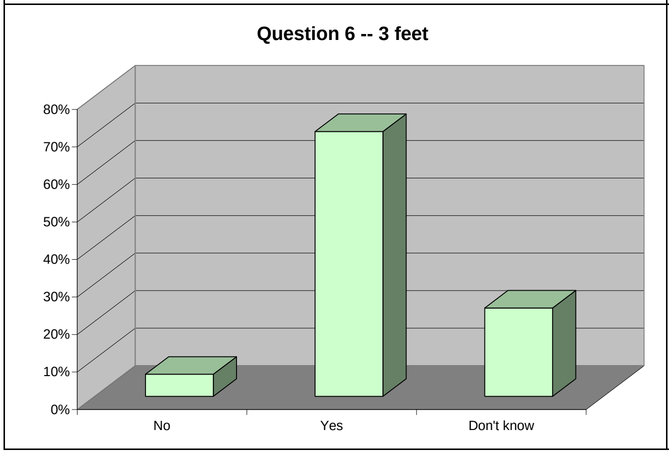
(5) Have you received any response from the public about paved shoulders?

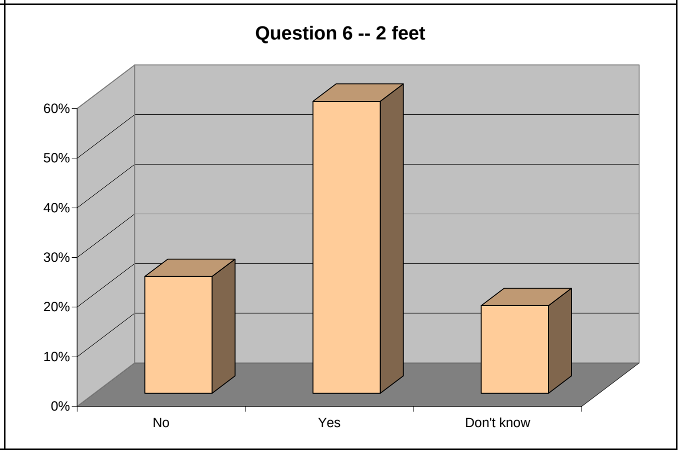


(6) Several widths of paved shoulders are used in Iowa. Is there a difference in reduced maintenance for these various widths?

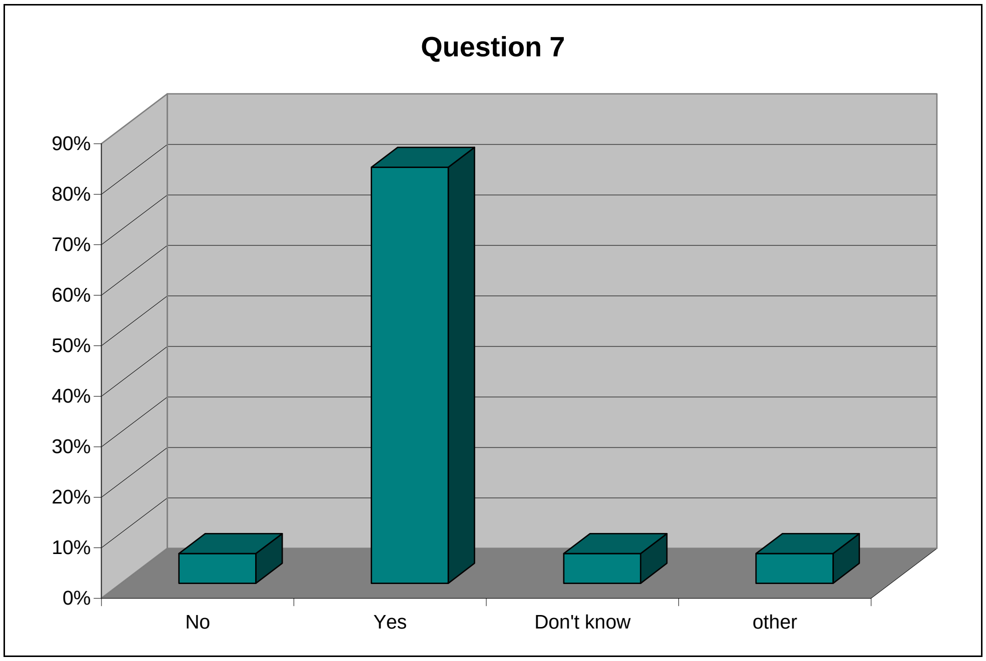




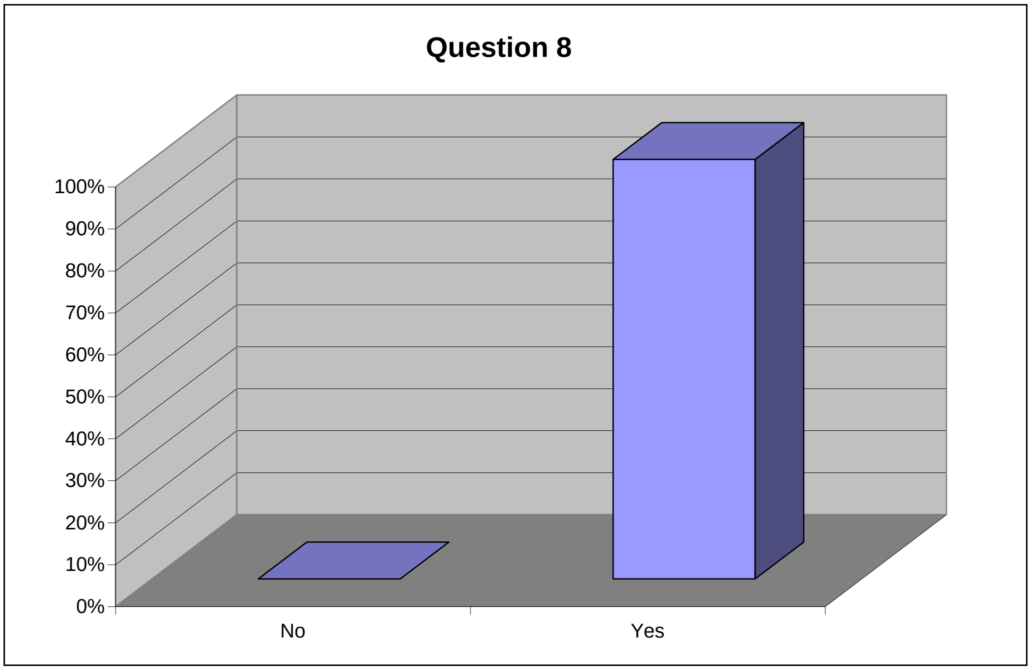




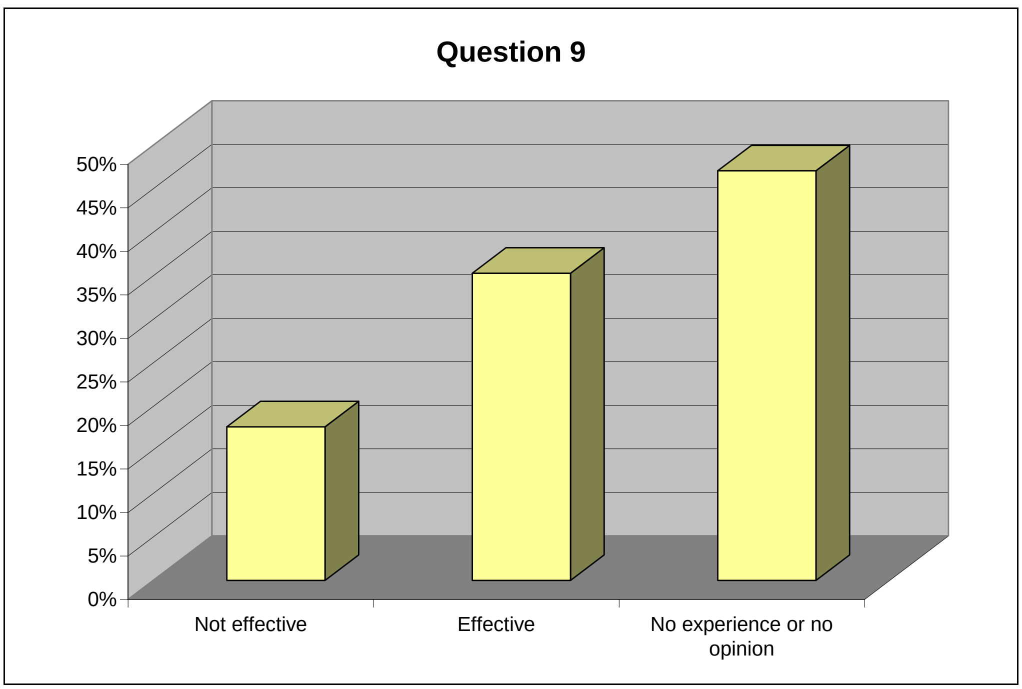
(7) Do you think rumble strips add to the effectiveness of paved shoulders?



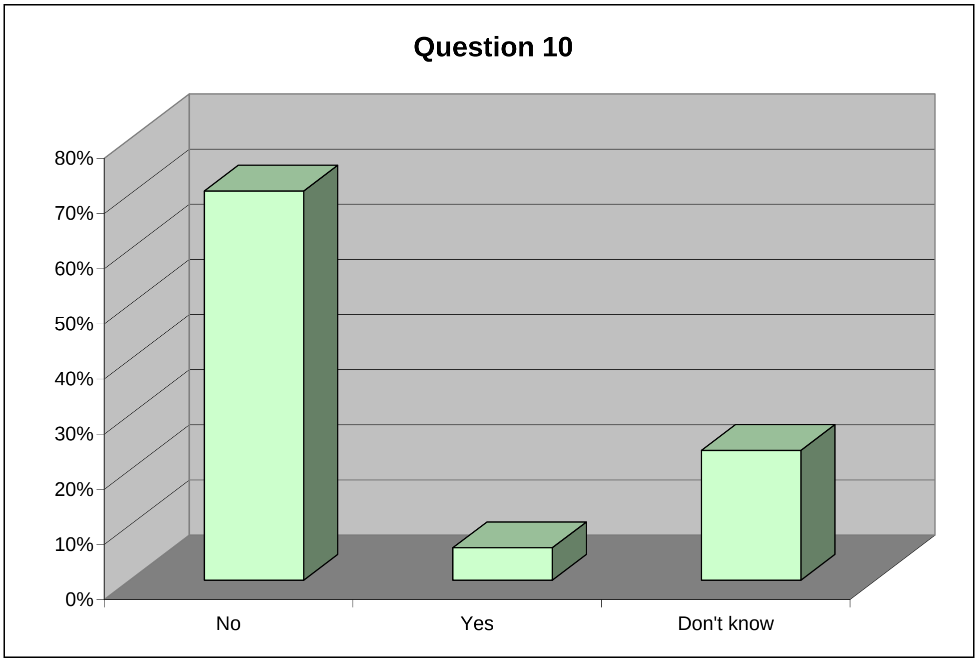
(8) Do you think edge rut paving placed by DOT maintenance is effective in reducing edge rutting and needed maintenance?



(9) Some districts have moved the painted edge line in about 1 ft instead of placing narrow paved shoulders. What do you think of this practice in terms of reduced edge rut maintenance?



(10) Have you or your crews experienced any close calls where paved shoulders proved beneficial in avoiding an accident?



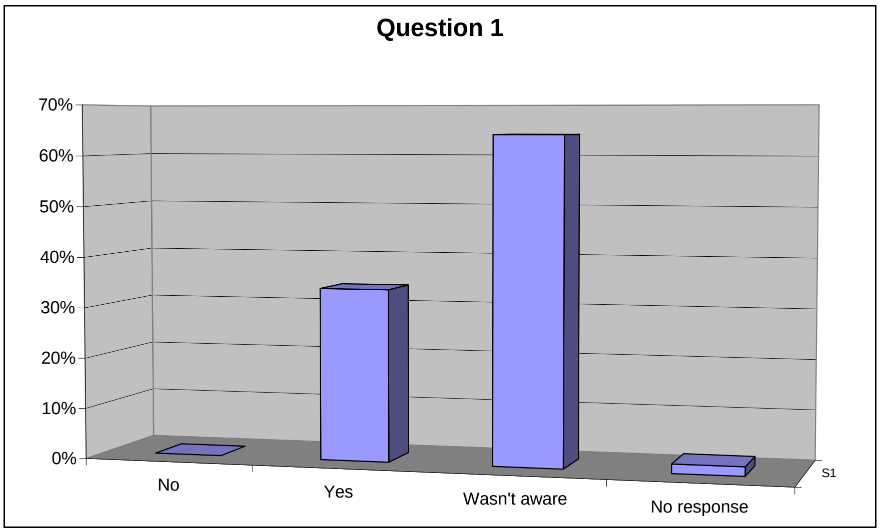
Comments received include the following:

- "We tried several years ago to prove the benefit of paving shoulders full or partial width on discrete roadways. Basically management was not receptive to this, but in all fairness it is also difficult to assess the benefit to us (maintenance forces)."
- "District *"X"* has three supervisors with lane miles where the edge lines were moved in and all three state that this improved the edge rutting problem and [was] an effective way to reduce costs."
- "People believe the shoulder is the rock portion, and so unless [it is] full width they move right until they are off the pavement. This can cause additional maintenance for repair and fixing of the outside shoulder edge."
- "The wider roads with the inset edge line and rumble strips make for nice driving and appear to be a possible remedy to a lot of our immediate edge rut issues. I would sure like the opportunity to try these on some of my routes."
- "Paved shoulders should be a minimum of three feet. The paved shoulders reduce the time we have to blade in edge ruts. Also, paved shoulders are a safety factor in reducing the edge ruts, and with rumble strips it helps motorists in driving."
- "The cost associated with edge rut maintenance is difficult to determine because: (1) stone (material) cost is charged out when receipted for, i.e., we do not record the amount of material actually used, and (2) we should be able to determine labor and equipment."
- "Bituminous shoulders seem to have higher costs associated with them than do PCC shoulders, but that is certainly because of the thickness and mix design originally used."

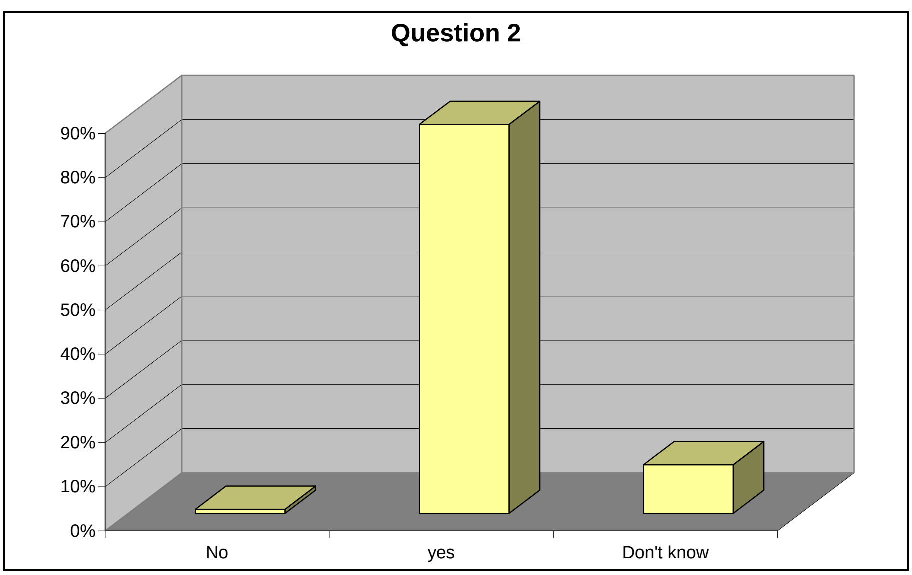
3.2 Survey of Law Enforcement

Law enforcement personnel have first-hand experience visiting crash scenes. It was felt that they may have expert opinions about whether the use of paved shoulders has resulted in fewer or less severe crashes. A survey was sent to a number of law enforcement personnel to seek their opinions using the questions provided below. A total of 109 officers responded. Results for each question are summarized following each question.

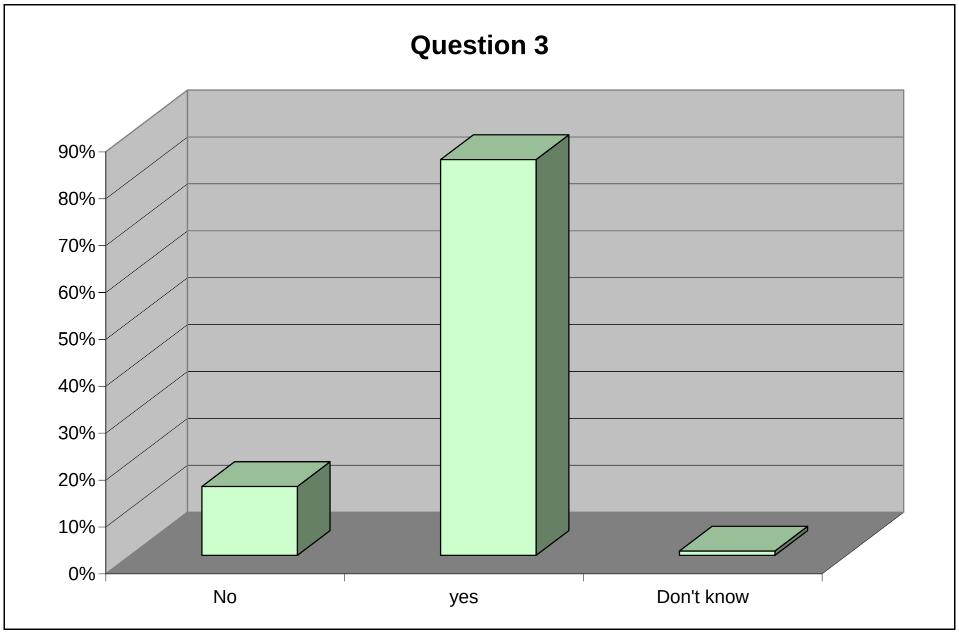
(1) Approximately three years ago, the Iowa DOT adopted paved shoulder guidelines for new and rehabilitated roads in Iowa. Do you approve of these guidelines?



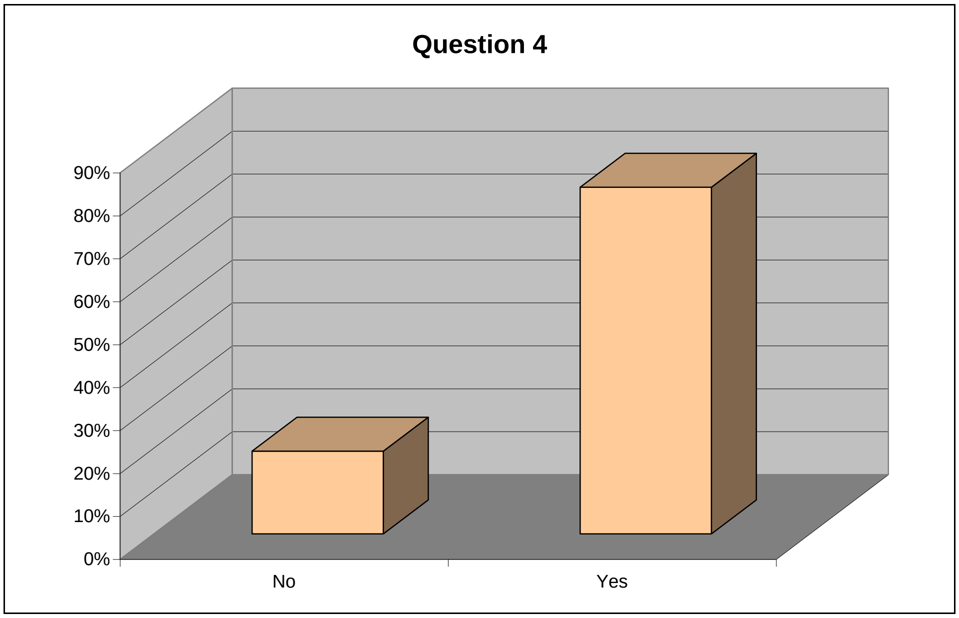
(2) Do you think paved shoulders reduce the incidence of run-off-road crashes and improve safety on Iowa's highways?



(3) Have you investigated crashes where edge drop off possibly contributed to the loss of control of the vehicle?



(4) Does the presence of paved shoulders have any effect on law enforcement?



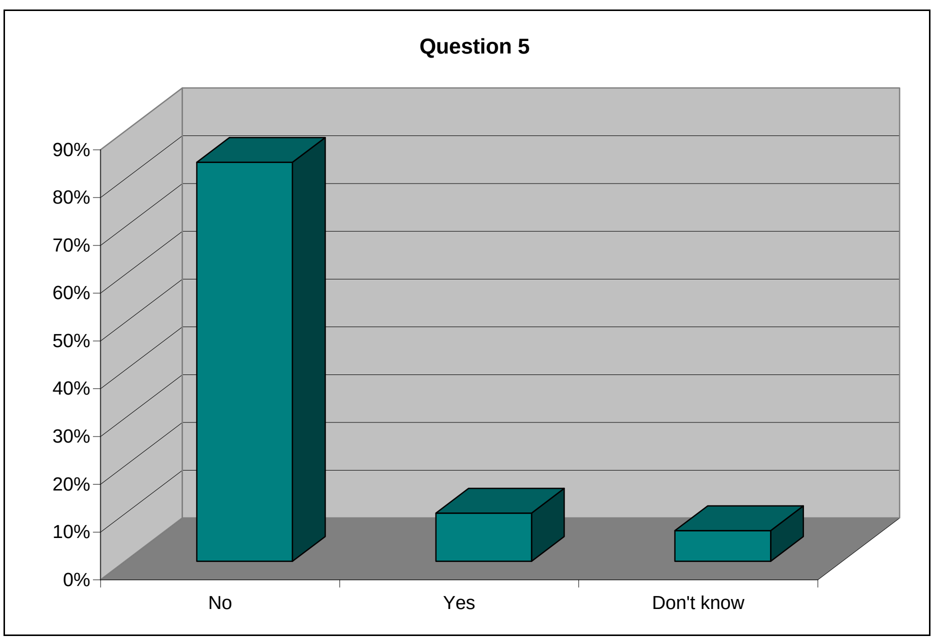
The following are specific responses as to why the respondents to Question 4 felt the paved shoulders had an effect:

- “Provides good location for violator stops”
- “Easier to do traffic stops in bad weather”
- “Safety for everyone”

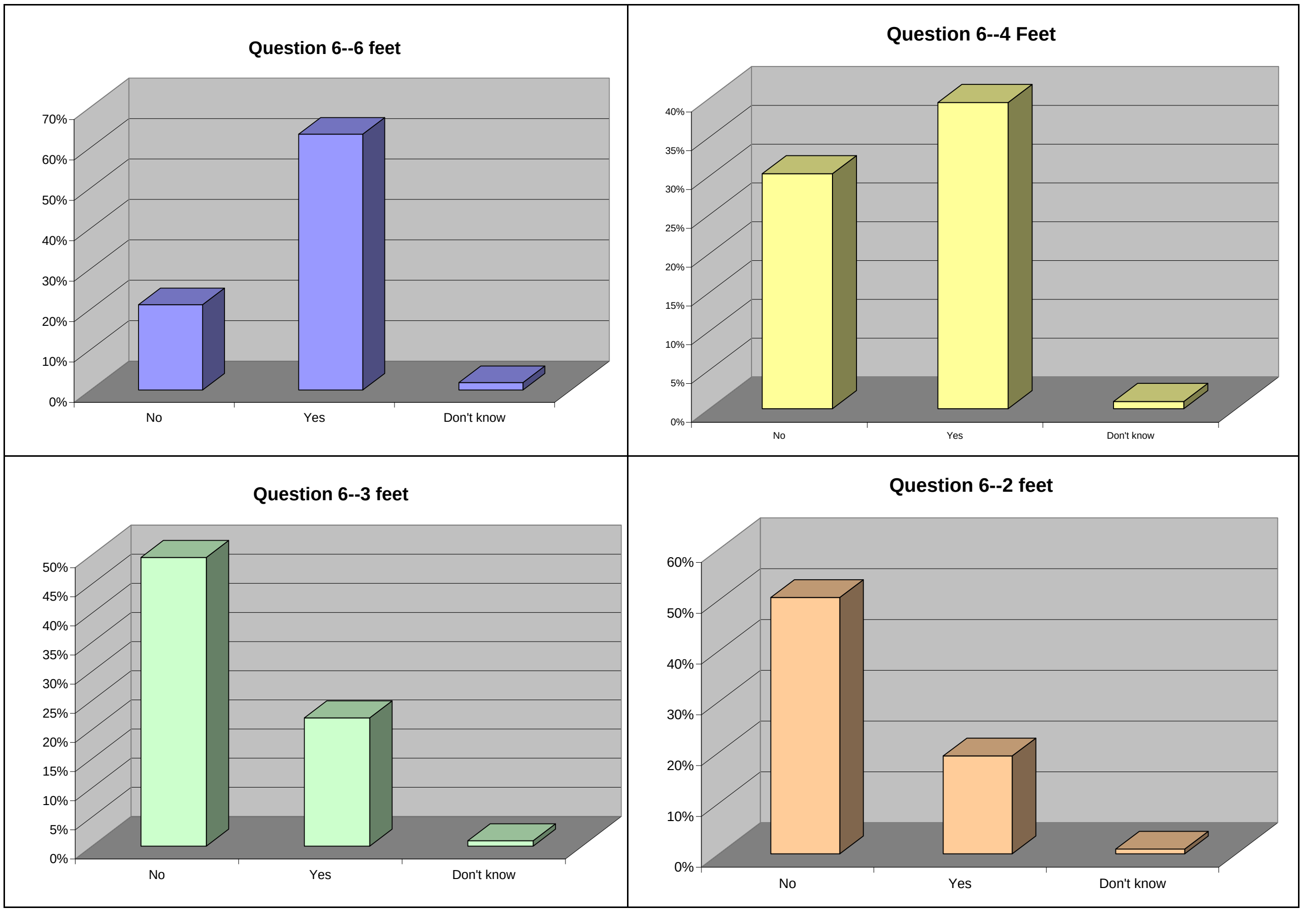
- “May invite passing on the right/shoulder”
- “Allows motorists to pull over on a paved surface when an emergency vehicle running code comes up behind them. Also provides a more stable platform for conducting traffic stops”
- “Should save on accidents of question #3”
- “Officer safety during stops or assisting motorists”
- “If the shoulders are gravel and wet, driving onto them could cause the patrol car and violator may get stuck. With paved shoulders there is a less likely chance of getting stuck.”
- “They are more safe to patrol and there is a better surface to perform standard field sobriety testing (OWI tests) on.”
- “Creates a better environment for officer safety”
- “We use them for turning and abandoned vehicles.”
- “Give more room and better footing when doing approach to traffic stops”
- “Makes turning around safer and allows violators to exit and/or re-enter traffic easier.”
- “I believe it is safer pulling cars over on paved shoulders and is much safer while conducting OWI investigations.”
- “Cleaner cars, safer OWI sobriety tests”
- “Giving people a place to pull off roadway if vehicle breaks down is a good idea.”
- “Safer for traffic stops and would think possibly help prevent accidents”
- “Provides for more safety during traffic stops”
- “Safer turn-around to pursue violators. Safer area for traffic stops and stalled motorists”
- “Not aware of any paved shoulders in Tama County”
- “Safety with vehicles stopped”
- “Reduce overcorrecting accidents”
- “Allows easier turn-around maneuvers to stop violators”
- “Helps with controlled braking when trying to get on shoulder quickly”
- “Paved shoulders present more available roadway to make safe vehicle stops, leaving the traveled portion open to the motoring public.”
- “Safer for traffic stops”
- “Easier to do roadside sobriety tests”
- “Provided the shoulders are wide enough, it allows us to sit at roadside and run radar and maintain traffic.”
- “It provides a safer place for motorists to pull over out of the way of emergency vehicles.”
- “A good surface to conduct OWI SFST’s/vehicle weight”
- “We have one section in town where, because of the fog line, persons think there's an additional traffic lane.”
- “Easier turnarounds, safer environment”
- “Makes traffic stops and motorist assists easier and safer”
- “Safer environment to pull cars over and for disabled vehicles”
- “Safety of officers during traffic stops”

- “Makes it easier to jack-up a car for flat tires, helps in making turnaround to chase violators, stranded motorist, list could go on with more room.”
- “Wider turn around, better footing, etc.”
- “Less accidents”
- “Makes for easier pull overs on stops”
- “Presumably fewer drop off/loss of controls”
- “Better shoulders make it easier to turn around.”
- “Extra measure of traffic safety for public as ourselves”
- “Less crashes—wider shoulders are safer for traffic enforcement.”
- “Provides a safe pull off point for traffic stops or 10-50 investigations”
- “Safer and easier to work traffic enforcement”
- “Allows drivers to make mistakes by going off the road. Soft shoulders wouldn't be as forgiving.”
- “Safer place to pull vehicles over—possibly reduce accidents”
- “Continuous turning around on shoulder and the safety of standing on and working on a hard shoulder”
- “Safe place to pull over vehicles”
- “Hopefully decreases accidents—safer environment for traffic stops”
- “Safer roadways—less accidents”
- “When there are problems it is easier to have more shoulder room, it also makes it safer in the winter.”
- “Safer environment to work from”

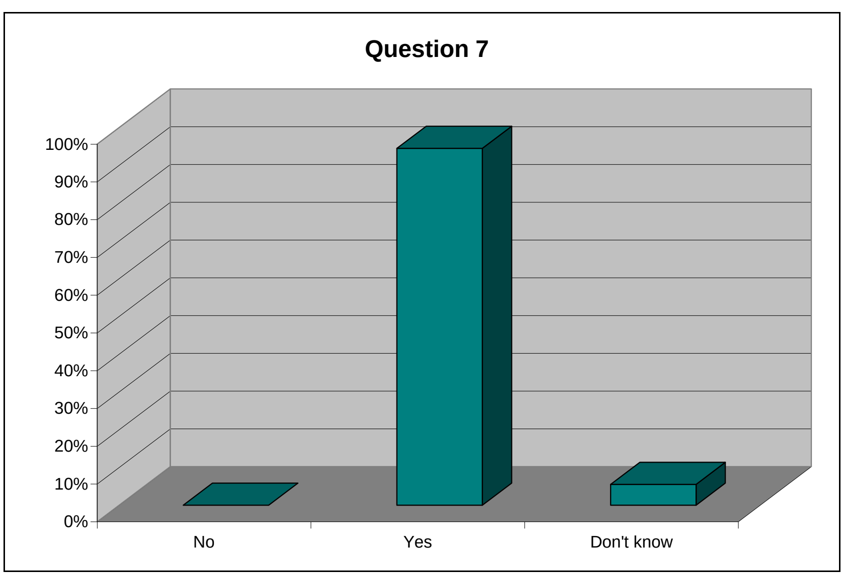
(5) Have you received any response from the public about paved shoulders?



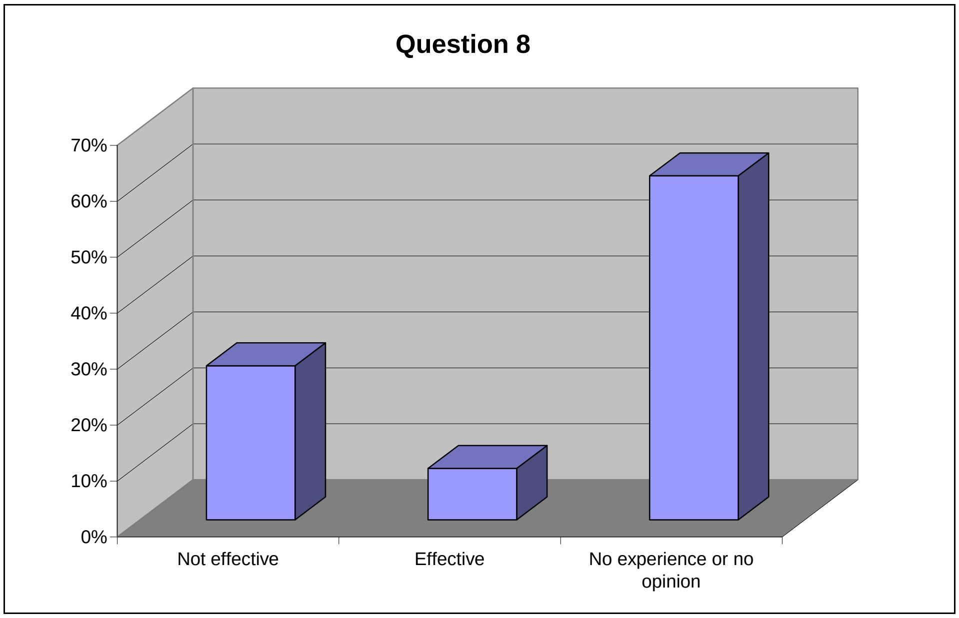
(6) Several widths of paved shoulders are used in Iowa. Is there a difference for law enforcement activities from these various widths?



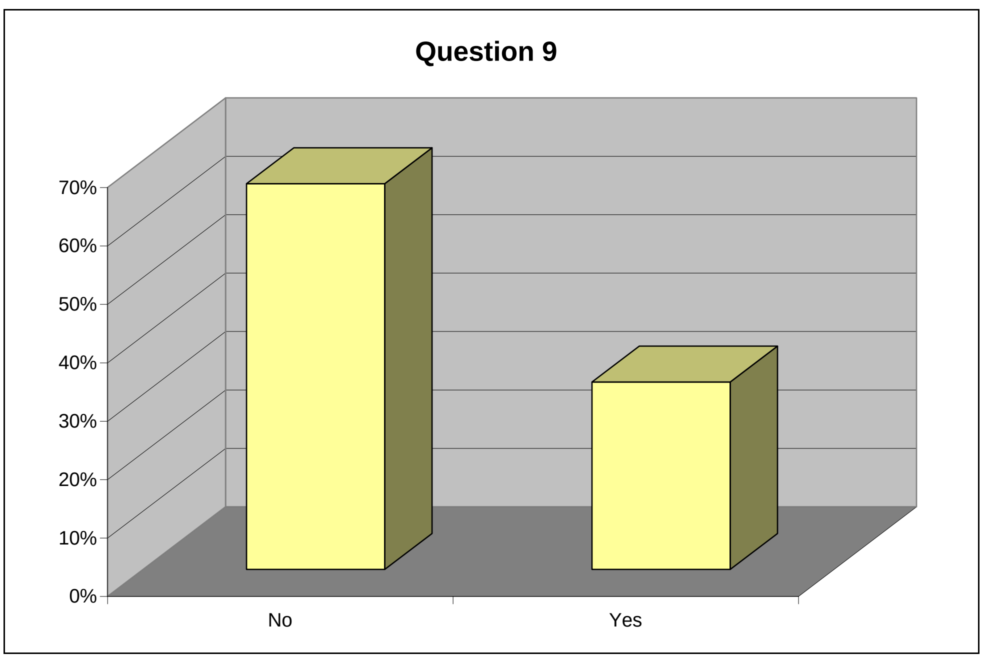
(7) Do you think rumble strips add to the effectiveness of paved shoulders?



(8) In some Iowa DOT districts, painted edge lines have been moved in about 1 ft instead of placing narrow paved shoulders. What do you think of this practice in terms of reducing run-off-road crashes?



(9) Have you experienced any close calls where paved shoulders proved beneficial in avoiding a crash or personal injury?



4. DATA COLLECTION

The main objective of this project was to conduct a before and after crash analysis for locations where paved shoulders have been included in maintenance or resurfacing, restoration, and rehabilitation (3R) projects. A total of 277 segments of road data were collected as described in the following sections. Data were collected in 82 counties. Data were collected for segments that had paved shoulders and for a smaller group of similar roadways that did not have paved shoulders, which were used as control sections for the statistical analysis.

4.1 Identification of Potential Locations

Engineers from each district in Iowa were contacted in an effort to identify sections of paved shoulders within the State of Iowa. The information received from the engineers was combined with a list of recent 3R projects from fiscal year 2000 through fiscal year 2006 that was obtained from the Iowa DOT. Sections listed as widening projects or those listed as receiving a paved shoulder in the description were selected as potential sites.

In addition to the information received from the Iowa DOT, any locations that the team or the Iowa DOT project monitor were aware of or any locations encountered during site visits were also included. A paved shoulder was defined as a shoulder that had at least 1 ft of paved material beyond the painted edge line. This definition was to distinguish a location with intentional paving from a location where the edge line inadvertently varied as it was laid.

4.2 Data Collection

Once the list of potential locations was compiled, each site was visited and roadway data were collected. Data were usually collected in at least two locations to ensure uniformity of the section. Typically, data were collected at a spot one or two miles after the paved shoulder section began and then was collected approximately every two to four miles thereafter. Frequency of data collection depended on the confidence of the data collector in the uniformity of that section.

Beginning and ending points of roadway sections were determined by profile and construction year uniformity. Clearly, a segment began and ended when a paved shoulder started or stopped. In addition to this criterion, however, differences were looked for along the roadway to ensure construction year uniformity. If a segment changed pavement type, then the segment ended not only because of the difference in pavement, but because the sections were most likely constructed in different years. Obvious changes in pavement color or construction techniques, such as rumble strip type or presence, were also cause for a segment to end for construction year uniformity. Finally, speed limit changes and segment length were reason to end a section. Once a section reached about 12 miles in length, it was ended to maintain some uniformity in the section lengths being studied. Additionally, after data were collected, several sections were split into smaller sections if annual average daily traffic (AADT) varied significantly along the section.

The following information was recorded at each location where data were collected using a data collection form:

- Speed limit

- Orientation (i.e., N/S)
- Pavement type
- Shoulder type
- Shoulder pavement type
- Unpaved shoulder type
- Rumble strip type
- Rumble strip location
- Total paved width
- Paved shoulder width
- Unpaved shoulder width
- Presence of paved driveway entrances or widening on curves
- Anything unusual about roadway

Date, county, and a detailed literal description of the segment of roadway were noted at each location. The location of each "sample" of data within a segment was also noted. The roadway segment, including locations of each individual data collection location, was also marked on a detailed map of Iowa at the time of data collection. This was done to ensure the correct location was found later when identifying locations in GIMS files. Finally, a picture was taken at each data collection location for reference if there was any question about what was collected. A description of how each characteristic was collected is provided in the following sections.

4.2.1 Speed Limit

When speed limits were not posted, a speed limit of 55 mph was assumed (2007 Iowa Code §321.285) (Iowa 2006–2007).

4.2.2 Orientation

North/south and east/west orientations were collected on a spot by spot basis. If a roadway segment was oriented predominantly north/south but a sample was collected on an east/west portion, then the portion was collected as east/west with a note that the overall segment is north/south. For segments that were aligned diagonally, the general orientation of that highway as a whole was looked at or judgment was used to determine which orientation to mark.

4.2.3 Pavement Type and Shoulder Pavement Type

Asphalt and concrete pavement types were collected for this project. No bituminous seal coat or other types of pavements were collected.

4.2.4 Unpaved Shoulder Type

The unpaved portion of the shoulder was considered to be gravel, earth, or mixed. Gravel shoulders, shown in Figure 4.1 were those that still clearly had some gravel cover. Earth shoulders, shown in Figure 4.2, were either dirt shoulders or grass shoulders. Finally, mixed shoulders (Figure 4.3) were shoulders with some gravel cover but also some grass growing through or a significant amount of dirt showing. The mixed category was only used when neither of the other categories seemed to apply.

Figure 4.1. Typical gravel unpaved shoulder type

Figure 4.2. Typical earth unpaved shoulder type

Figure 4.3. Typical mixed unpaved shoulder type

4.2.5 Shoulder Type

A roadway segment was marked as having a fully paved shoulder if the paved shoulder width was approximately 6 ft or greater, as shown in Figure 4.4. Any road with between 1 and 6 ft of paved shoulder was considered as having a partially paved shoulder. An example of a partially paved shoulder is shown in Figure 4.5. Any amount of pavement less than 1 ft beyond the painted edge line was considered unpaved, shown in Figure 4.6.

Figure 4.4. Two-lane highway with fully paved shoulders

Figure 4.5. Two-lane highway with partially paved shoulders

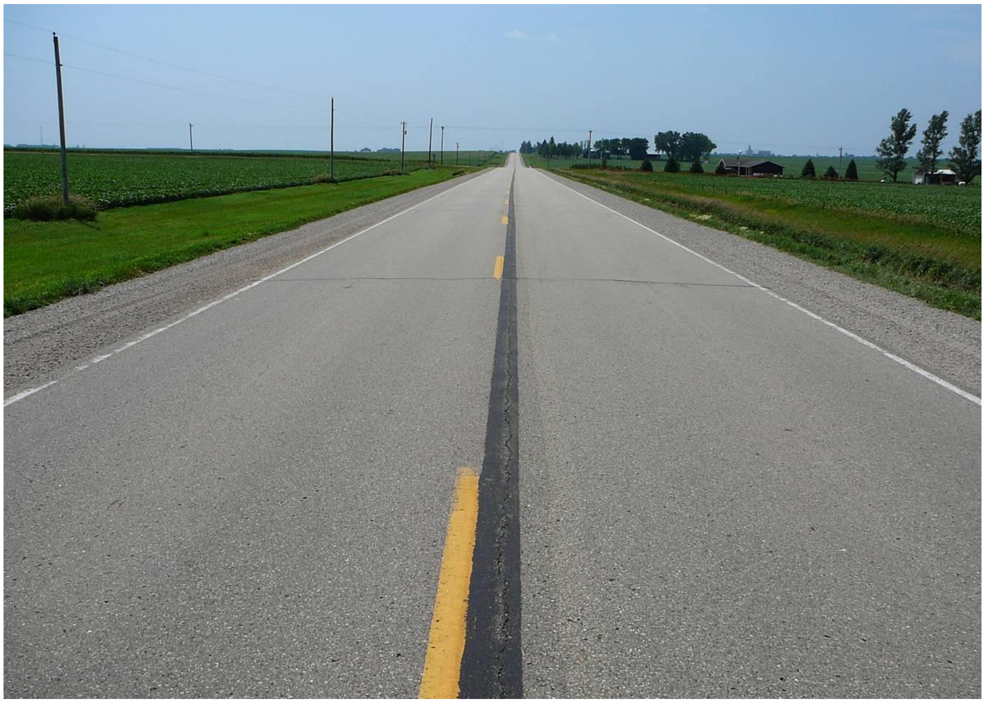


Figure 4.6. Two-lane highway with unpaved shoulders

4.2.6 Rumble Strip Type

When present, rumble strips were categorized as rolled, milled, or formed. Rolled rumble strips are found on asphalt roadways, and formed rumble strips are their concrete roadway counterpart. Rolled rumble strips are not as common, however, as they are generally considered less effective than milled rumble strips in asphalt. Images of rolled, milled, and formed rumble strips are provided in Figures 4.7 to 4.9.

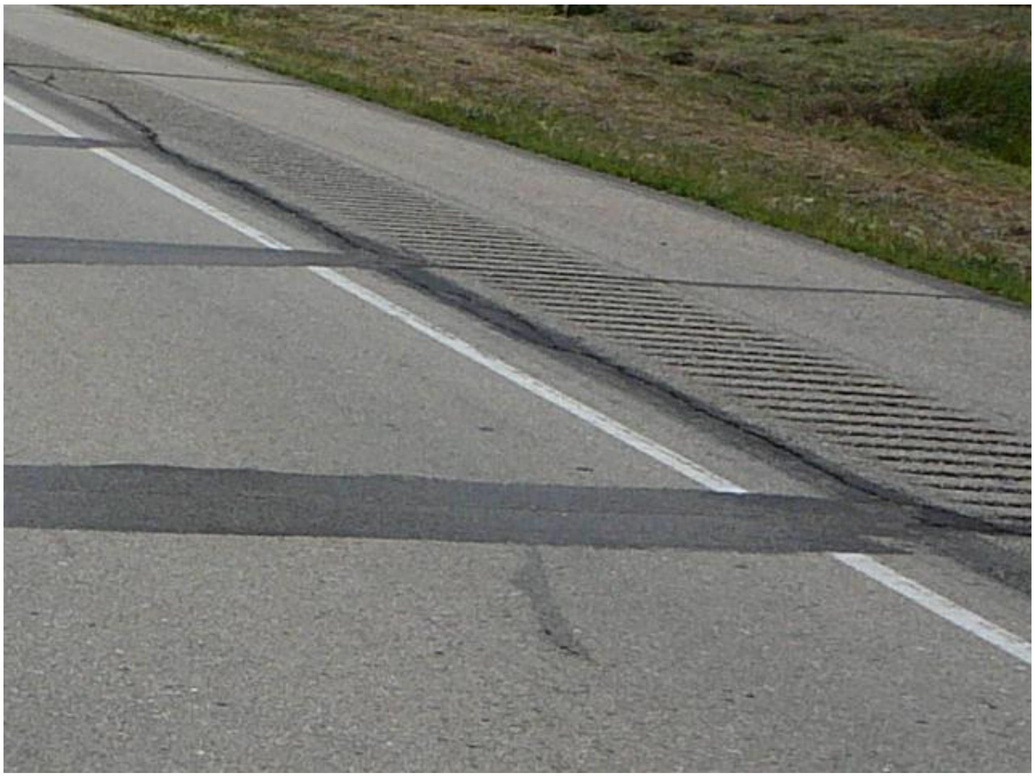


Figure 4.7. Rolled rumble strips

Figure 4.8. Milled rumble strips

Figure 4.9. Formed rumble strips

4.2.7 Rumble Strip Location

Rumble strips were recorded at the edge of the paved lane, at the edge of the paved shoulder, or at some distance from the edge of the paved shoulder. Edge line rumble strips were recorded at the edge of the paved lane.

4.2.8 Total Paved Width

Total paved width was measured from the edge of the pavement to the edge of the pavement, regardless of the presence of paved shoulders. Paved shoulder width was also measured, and lane width was determined by subtracting paved shoulder width from total width and dividing by two. A measuring wheel or tape measure was used to make the measurements.

4.2.9 Paved Shoulder Width

The paved shoulder width was measured from the edge of the pavement to the outside edge of the painted edge line. In the absence of a painted edge line, measurement was made from the outside edge of the pavement to the transition of the shoulder pavement type to the mainline pavement type. However, the absence of a painted edge line was rarely, if ever, an issue. This measurement was made with a tape measure.

4.2.10 Unpaved Shoulder Width

The distance from the break in grade to the edge of the pavement was considered the unpaved shoulder width. This measurement was also made with a tape measure. It is often difficult to determine where the break in grade occurs, as it may have rounded off over the years due to erosion. When this was the case, judgment was used to look up and down the highway to determine the best possible point to declare as the break in grade. This was potentially the source of the variation in unpaved shoulder width experienced on some roadway segments.

4.2.11 Presence of Driveway Entrances or Widening on Curves

It was noted as a yes or no if any paved driveway entrances were present along the segment of roadway. It was also noted as a yes or no if any curves along the section of road experienced any widening. Some roadways have an additional 1 or 2 ft of paved shoulder on the inside and/or outside edge of curves. This is done to help keep cars on the pavement and to prevent edge rutting that commonly occurs on curves.

4.2.12 Anything Unusual about Roadway

Any other types of random widenings or noteworthy unusual characteristics of the roadway were described under this category. The most common entries here were the presence of single or multiple bridges and the presence and location of left- and/or right-turn lanes. Other things noted include, but are not limited to, the following: interchanges, guard rails if they were present for a significant length of time, unusually steep or shallow grades beyond the shoulder, whether the highway was access controlled, school zones, whether housing was present along part of the road, temporary pavement changes, temporary shoulder width changes, unusual signs that would affect driving habits, and anything else that could affect how people drive or the amount of shoulder-related crashes that occur.

4.3 Determination of Construction Year

Data for each section were entered into an Excel spreadsheet. The corresponding road segments were selected in the Iowa DOT GIMS database. GIMS segments corresponding to each collected section were coded with a unique ID ("Paved ID") using ArcView. Each section was double-checked against a map to ensure that they were located in the correct location in GIMS, and the database was updated as needed.

4.3.1 Fiscal Year of Construction

After the data were refined and accurately reflected their original collection location, the fiscal year in which paved shoulders were added during construction was determined. This step was essential for before and after analysis. It was not possible to locate specific calendar dates of construction; however, the fiscal year of construction was noted. Most construction in Iowa takes place during the summer months. This allows for sufficient time on either side of the probable construction time frame to ensure the construction period did not start before or continue past the officially listed fiscal year in which the road was constructed.

The fiscal years of construction were obtained from two main sources: the 3R files obtained from the Iowa DOT and the *2004 Test Sections by Milepost* book, also obtained from the Highway Division of the Iowa DOT. The 3R files consist of Microsoft Excel workbooks that contain six worksheets of data, one worksheet per district in Iowa. The worksheets list projects associated with that file, organized by county and by route number, that were constructed during the year, as well as projects that were scheduled for future years. The lists contain literal descriptions of project limits, project costs, whether or not the project was let that year, and a description of the work done. These files were the first choice for determining fiscal year of construction, but when segments were not found in these files, the *2004 Test Sections by Milepost* book was checked.

The *2004 Test Sections by Milepost* book contains a list of every project constructed on a state route since the routes' initial construction. The book is sorted by county, and projects are listed from milepost to milepost, with a map of each county showing the mileposts mentioned in the project listings. Next to the milepost boundaries are the directions of the roads for four-lane divided highways, the year of construction, the project number, and information about the pavement used for the project. This source was very effective for determining construction years on older projects, as well as any other project on a state route that was overlooked or not included in the 3R files.

Finally, the third source of information was county engineers. If a paved shoulder was collected on a non-state route, then county engineers were contacted via email. The county engineers were quick to respond with the information requested.

4.3.2 Length

The length of each segment was obtained from the segments selected in the GIS database. The GIS lengths are stored in meters and converted to miles.

4.4 Data Preparation

A total of 256 treatment and control segments were collected. Data for each location were entered into a database and spatially located using the Iowa DOT's GIMS database.

Several locations were dropped from the analysis because they could not be located in the GIMS database or because the year paved shoulders were added could not be determined. Several locations had paved shoulders that were installed before the study period began in 1984. These sites were removed from the analysis because there was no before and after period. This resulted in a total of 220 sites analyzed, including 77 control sections and 143 test sections.

The location of sections collected is shown graphically in Figure 4.10. This map includes both paved shoulder sections and control sections.

Initially a month was the time interval modeled. This unit allows the effect of time of year to be included, because it is expected that some seasonal pattern may be evident in lane departure crashes. Dr. Michael Pawlovitch of the Iowa DOT created code to extract crash and volume data by month, starting in January 1984 and ending in December 2007. Total crashes, cross centerline crashes, and single vehicle ROR crashes were extracted from the Iowa DOT crash database for each segment by month. Crashes that corresponded to each section were selected using a manual process in a GIS, ArcView. AADT was selected for each section for each year. When AADT varied along a section, a weighted average was calculated. Monthly volume was determined by multiplying AADT by the number of days for that month. AADT was obtained from archived snapshots of the Iowa DOT's GIMS database.

After an initial analysis was conducted, it was determined that use of months resulted in a large number of observations with zero crashes. Data were combined into quarters. Volume data were also aggregated by quarter. Data were aggregated for months where weather in Iowa was the most similar resulting in the following:

- Winter: (Dec, Jan, Feb)
- Spring (March, April, May)
- Summer (June, July, August)
- Fall (September, October, November)

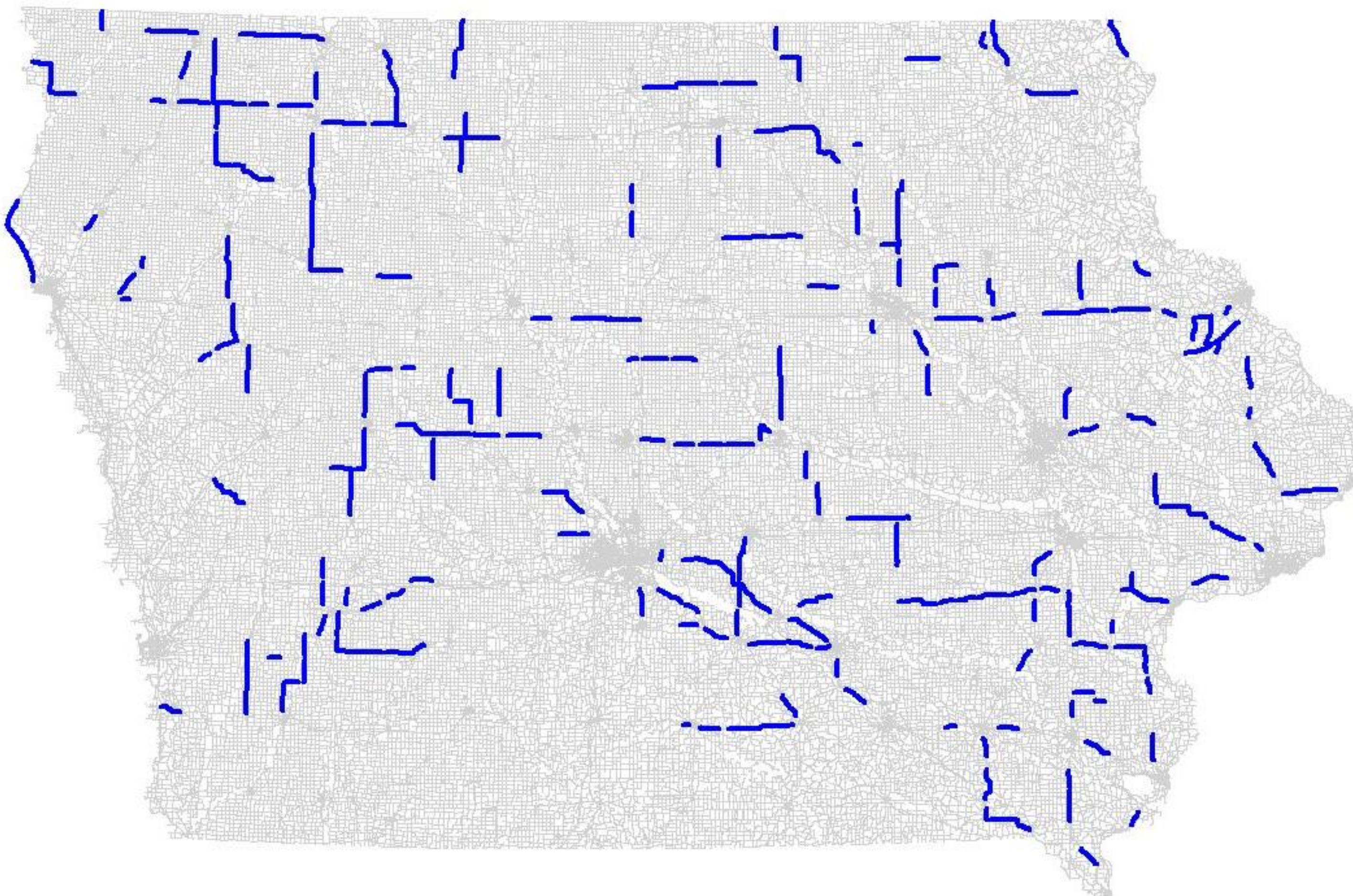


Figure 4.10. Location of sections collected

5. ANALYSIS

Generalized linear models were used to investigate the relationship between crash reduction and implementation of paved shoulders. The following provides a very general description of the model results. The models addressed overdispersion when present and excess zeroes.

A total of 224 sites were modeled with 147 sites receiving paved shoulders (test sites) and the remaining 77 sites were control sites where no shoulders were added at any point prior to 2007. It was discovered after conducting the model that one of the control sections had paved shoulders and it was removed from the sample since a construction date was not available. The dataset included 21,310 observations (rows). Correlations between observations from the same section were accounted for in the model and the correlations depend on time.

Separate models were developed for cross-centerline (CL) crashes, run-off-road (ROR) crashes which included all road departure crashes, and single vehicle run-off-road (SVROR) crashes which included only road departures involving a single vehicle. For each model the corresponding dependent variable was denoted as Y_{ij} which is the count of a specific type of event for the i^{th} section and the j^{th} time point. Each section of road has chronologically recorded number of crashes from 1984. There are correlations between records of the same section and the correlation may be time dependent meaning that correlation can exist between Y_{ij} and $Y_{i(j+1)}$ for the i^{th} section at two adjacent time points. So the value of Y_{ij} is used as a explanatory variable for the model of $Y_{i(j+1)}$.

5.1 Response Variable

The response variable was quarterly crash frequency. Traffic volume in total vehicles over the quarter (MT) was modeled as an offset. Segment length was modeled as an independent variable. As indicated, separate models were developed for different crash types.

5.2 Explanatory Variables

Table 5.1 shows the explanatory variables. Several other explanatory variables were available but were not included because they were highly correlated to other variables. For instance, median type was highly correlated to number of lanes because most four-lane road sections were also divided roadways.

Table 5.1. Explanatory variables for cross-centerline, ROR, and SVROR models

Variable	Value	Description
Polynomial of Year-1984	$(\text{Year-1984})^p$, p=1,2,…	A polynomial was used to explain the average change over years
after_trt	$I_{\{2\}}$(Period)	0 for periods before installation of paved shoulders 1 for periods after
Year_after_trt	Years after treatment	Year after treatment 0 for before period 0 for treatment year (year of interest – treatment year) for years after paved shoulders were installed (i.e. if shoulders are paved in 2002 and 2004 is of interest, then Year_after_trt = 2004 – 2002 = 2) This variable allows different slope of annual crash number trend before and after treatment. If the coefficient of this variable is negative, the averaged mean of crash number of treatment sections is lower than the averaged mean of sections without the treatment.
Indicator of seasons	$=I_{\{s\}}$(season), s=2,3,4	These three indicator variables are used for estimating the mean differences between seasons The value of I{2}(season)=1 if season=2 and the value is zero otherwise. 1 for Winter (December, January, February) 2 for Spring (March, April, May(3 for Summer (June, July, August) 4 for Fall (September, October, November)
Days	= total days during each season	
Is_RS	Indicates presence of shoulder rumble strip	0 if no rumble strip is present 1 if rumble strip is present
SpdLimit	Speed limit for section	
Tot_Rt_Shldr	Total length of right shoulder (paved plus unpaved)	in feet
RT_Pvd_Width	Total length of paved shoulder on right	in feet, 0 if no paved shoulder
RT_Unpvd_Width	Total length of unpaved shoulder	in feet
Polynomial of length	$=\sum_{i=1}^{p}(\text{length})^p$, p=1,2,…	length of each section P is the order of the polynomial. P=1, length is added as an explanatory variable.

		P=2, length2 is also added as an explanatory variable. P=3, length3 is also added as an explanatory variable.
Median	Median type	0 for undivided 1 for divided
Is_4lane	Indicates number of lanes	0 for 2-lane sections 1 for 4-lane sections
Is_div4lane	Indicator for 4-lane divided	0 if number of lanes = 2 0 if number of lanes = 4 and median = 0 1 if number of lanes = 4 and median = 1

5.3 Model for Total Crashes

A model was developed for total crashes where Y_{ijk} is total crashes per site. The best fit model was a zero inflated negative binomial model. The estimated variance and mean ratio was about 1.5. Estimated coefficients are shown in Table 5.2. As indicated, crashes are negatively correlated with the amount of right shoulder provided, presence of median (i.e. divided versus undivided), and amount of paved shoulder provided. The coefficient for "treatment" was not significant in the model and as a result, the effect of the treatment was not immediate. The impact of incorporating paved shoulders is encapsulated in the predictors for "after_trt_year" and "Shd_Paved." The variable "after_trt_year" indicates a decreasing trend in crashes after paved shoulders were installed.

The effect of a predictor can be estimated by the coefficients. For example, the effect of median can be estimated by:

$$E(Y|median=1, x_{other}) / E(Y|median=0, x_{others}) = \exp(-0.342694) = 0.7$$

As indicated, the expected mean reduction in total crashes due to having a divided roadway versus undivided roadway is 30%.

Similarly the impact for each foot of additional right shoulder is given by:

$$E(Y|Tot\_RT\_Shldr=2, x_{other}) / E(Y| Tot\_RT\_Shldr=1, x_{others}) =$$

$$\exp(-0.044698*2 + 0.044698*1) = 0.96$$

Indicating a reduction in the estimated mean number of crashes by 4%.

Table 5.2. Estimated coefficients for the total crash model

Parameter for response model	DF	Estimate	Standard Error	t value	P(T > |t|)	Notes
Intercept	1	5.093213	3.510558	1.45	0.1468	
Tot_RT_Shldr	1	-0.044698	0.002885	-15.49	<.0001	
Median	1	-0.342694	0.039458	-8.69	<.0001	
SpdLimit	1	-0.012490	0.003911	-3.19	0.0014	
Shd_Paved	1	-0.087671	0.027485	-3.19	0.0014	
after_trt_year	1	-0.010426	0.003180	-3.28	0.0010	
season1	1	-0.179793	0.037211	-4.83	<.0001	
season2	1	-0.235078	0.044686	-5.26	<.0001	
season3	1	-0.247293	0.044636	-5.54	<.0001	
Year-1984	1	-0.004523	0.001395	-3.24	0.0012	
pre_CRASH_SITE	1	0.043465	0.003497	12.43	<.0001	This is the count of crashes in the previous period of time.
LENGTH	1	0.257575	0.009817	26.24	<.0001	
$LENGTH^2$	1	-0.008745	0.000598	-14.62	<.0001	
DAYS	1	-0.184256	0.038480	-4.79	<.0001	
Parameter for zero model						
Intercept	1	-2.218691	0.133599	-16.61	<.0001	
pre_CRASH_SITE	1	-1.205221	0.297076	-4.06	<.0001	
Parameter for over-dispersion						
α (variance=$\mu+\alpha\mu$)	1	0.487258	0.015759	30.92	<.0001	This means the variance is about 1.5 times the mean.

The predictor "after_trt_year" = max(0, year – trt_year)*I(in treatment group) has positive values only in the treatment groups. The "after_trt_year" explains the change of in estimated mean crashes after the treatment is applied. The coefficient of "after_trt_year"(-0.010426) explains the reduced trend after treatment. The effect of the covariate "after_trt_year" depends on time.

The coefficient "Shd_Paved" is the change in crashes due to each additional foot of paved shoulder added. The total total impact of paved shoulders is the effect of each additional foot of paved shoulder explained by the covariate "Shd_Paved" plus the decreasing trend over time as explained by the covariate "after_trt_year." This can by illustrated by assuming a treatment year and year for evaluation. We will use a treatment year of 1995 and assume 1 foot of paved shoulder.

For no treatment, the estimated change in crashes for each year is given by:

$$\exp^{(-0.00452 * (\text{Year} - 1984))}$$

For years 1984 through 1995, the estimate is the same as for no treatment. From 1996 forward, the estimated change in crashes for each year is given by:

$$\exp^{(-0.00452 * \{Year - 1984\} + -0.01043 * \{Year - Treatment\ Year\} + -0.087671*1)}$$

The trend over time for the situation where no treatment is applied and for applying paved shoulders in 1995 is plotted in Figure 5.1. As indicated, there is a decreasing trend in total crashes over time independent of the treatment paved shoulders. However, once paved shoulders are added, there is an immediate reduction (approximately 8%) and then total crashes decrease at a higher rate (slope is more negative) thereafter. One year after treatment, the decrease in total crashes for sections with paved shoulders for each quarter is 8.9% greater than for no treatment. At 10 years, the decrease is 15.9% greater.

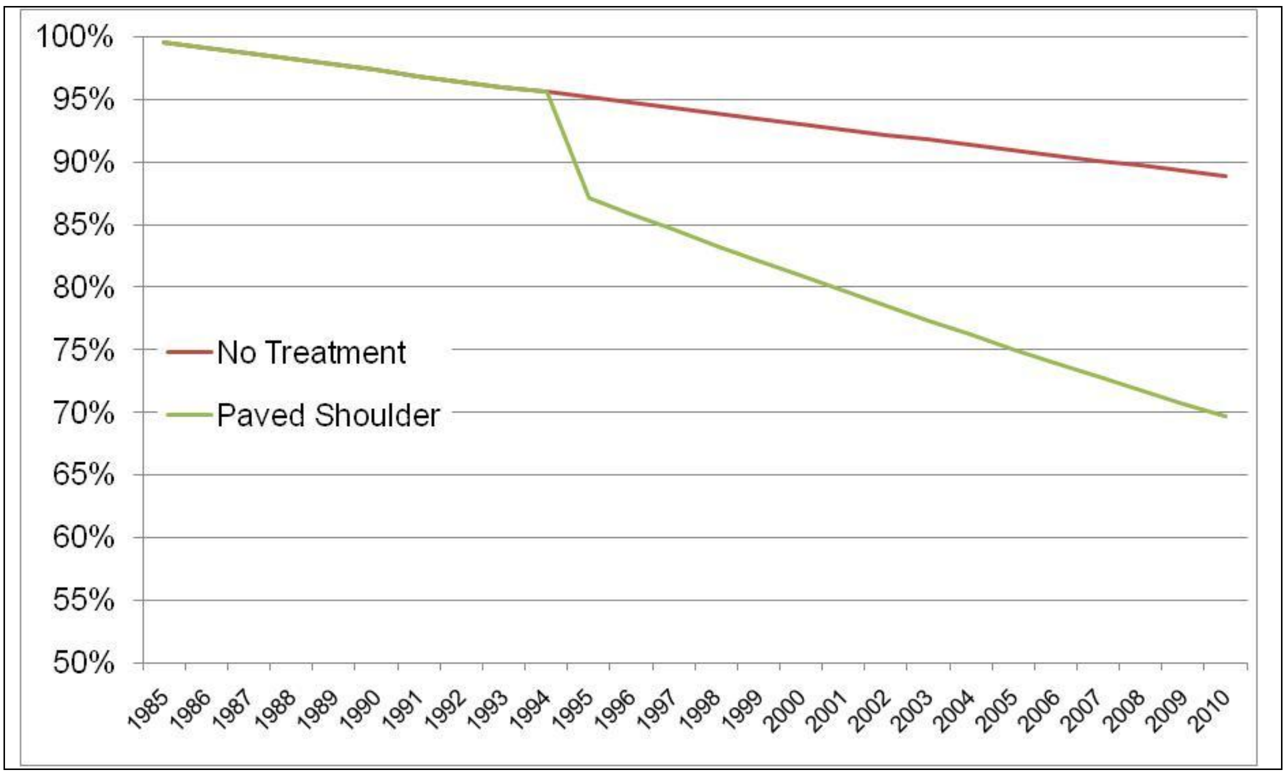


Figure 5.1. Decrease in crashes over time for situation where no paved shoulders are present versus having paved shoulders

5.4 Model for Cross-Centerline Crashes

The next model considered cross-centerline crashes. A large number of observations had zero crashes. A mixed model was first used which considered both over-dispersion and the mixture of zeros. However, it was determined that the model did not have a better fit than a negative binomial distributed (NB) model. As a result, the NB model was used.

The estimated variance and mean ratio was about 1.06. Estimated coefficients are shown in Table 5.3. As indicated, none of the covariates for paved shoulder were significant. As a result, addition of paved shoulders did not increase or decrease cross-centerline crashes.

Table 5.3. Estimated coefficients for the cross-centerline crash model

Parameter	DF	Estimate	Standard Error	t value	P(T > |t|)	Notes
Intercept	1	-19.116466	0.389285	-49.11	<.0001	
Tot_RT_Shldr	1	0.071060	0.020731	3.43	0.0006	
Median	1	-1.088505	0.130596	-8.33	<.0001	
season1	1	0.677462	0.141843	4.78	<.0001	
season2	1	-0.144779	0.164525	-0.88	0.3789	
season3	1	-0.089877	0.160994	-0.56	0.5767	
Year-1984	1	0.329842	0.045549	7.24	<.0001	
$(\text{Year-1984})^2$	1	-0.019573	0.002143	-9.14	<.0001	
LENGTH	1	0.331274	0.064926	5.10	<.0001	
LENGTH^2	1	-0.013269	0.003918	-3.39	0.0007	
Parameter for over-dispersion						
α (variance=$\mu+\alpha\mu$)	1	0.063870	0.025639	2.49	0.0127	This means the variance is about 1.06 times of the mean.

The model indicates that crashes are negatively correlated to total feet of right shoulder and presence of median. In this model, the effect of median was significant and can be estimated by:

$E(Y|\text{median}=1, x_{\text{other}}) / E(Y|\text{median}=0, x_{\text{others}}) = \exp^{(-1.088505)} = 0.3367$

As a result, cross-centerline crashes decrease by 66% when a divided median is present.

5.5 Model for Run-Off-Road Crashes

ROR crashes were modeled assuming the distribution of the response variable is a mixture of Poisson and zeros (ZIP). The over-dispersion coefficient was estimated and removed since the over-dispersion was not significant. Estimated coefficients are shown in Table 5.4.

The amount of total right shoulder available, presence of a divided median, speed limit and years after paved shoulders were installed were all statistically significant. Since the estimated probability of belonging to the zero model doesn't depends on other predictors, in this model, the effect of median can be estimated by:

$$E(Y|\text{median}=1, x_{\text{other}}) / E(Y|\text{median}=0, x_{\text{others}}) = \exp^{(-0.426923)} = 0.6525$$

Table 5.4. Estimated coefficients for the ROR crash model

Parameter	DF	Estimate	Standard Error	t value	P(T > |t|)	
Intercept	1	0.308047	5.124980	0.06	0.9521	
Tot_RT_Shldr	1	-0.081668	0.004896	-16.68	<.0001	
Median	1	-0.426923	0.061095	-6.99	<.0001	
SpdLimit	1	0.012535	0.006136	2.04	0.0411	
after_trt_year	1	-0.011187	0.003656	-3.06	0.0022	
Year-1984	1	0.011595	0.002171	5.34	<.0001	
season1	1	0.284322	0.056658	5.02	<.0001	
season2	1	-0.049749	0.068178	-0.73	0.4656	
season3	1	-0.055001	0.068095	-0.81	0.4193	
pre_ROR_SITE	1	0.071761	0.012818	5.60	<.0001	The value of ROR_Site at previous time point
LENGTH	1	0.257049	0.015606	16.47	<.0001	
$LENGTH^2$	1	-0.008725	0.000938	-9.30	<.0001	
DAYS	1	-0.163023	0.056132	-2.90	0.0037	
Parameter for zero model						
Intercept	1	-1.070874	0.074979	-14.28	<.0001	Indicates that there is about 0.25 probability that the record came from the model with P(0)=1.

As a result, around 35% fewer crashes are expected to result with a divided median versus having no divided median. It should be noted that presence of a median or not is correlated to number of lanes which was not included in the model.

The predictor "after_trt_year" = max(0, year – trt_year)*I(in treatment group) has a positive values only in the treatment groups. The "after_trt_year" explains the change of in estimated mean crashes after the treatment is applied. The coefficient of "after_trt_year"(-0.011187) explains the reduced trend after treatment.

If a treatment year of 1995 is assumed, a plot showing the different is generated using the following:

For no treatment, the estimated change in crashes for each year is given by:

$$\exp^{(0.011595 * (\text{Year} - 1984))}$$

For years 1984 through 1995, the estimate is the same as for no treatment. From 1996 forward, the estimated change in crashes for each year is given by:

$$\exp^{(0.011595 * \{\text{Year} - 1984\} + -0.01119 * \{\text{Year} - \text{Treatment Year}\})}$$

The change in crashes over time is shown in Figure 5.2. As indicated, ROR crashes per quarter are increasing over time independent of the treatment of paved shoulders. However, once paved shoulders are added, the average number of ROR crashes decreases at a low rate while sites where no treatment is present continue to increase over time. One year after treatment, the increase in ROR crashes is 1.3% less than for no treatment. At 10 years, sites with paved shoulders have 13.5% fewer ROR crashes than control sites.

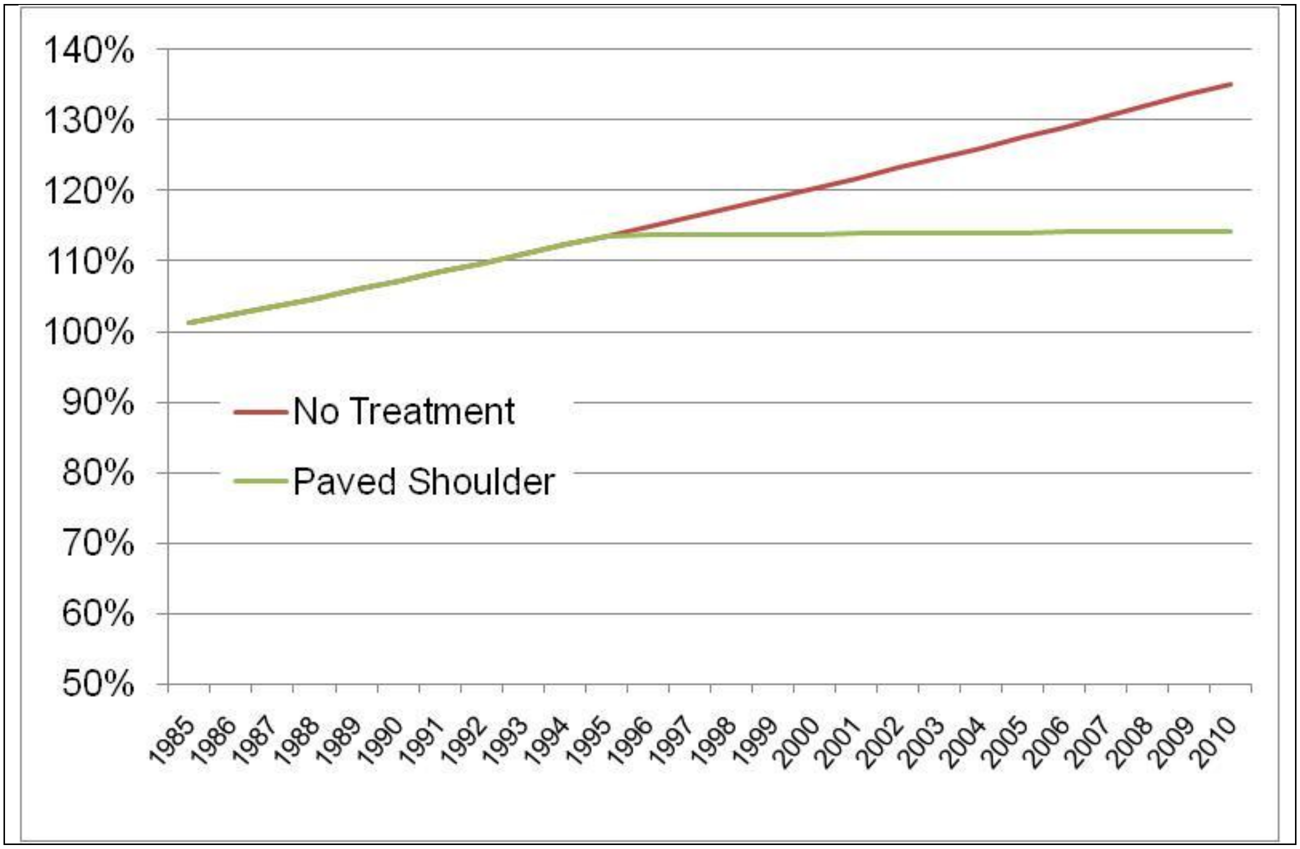


Figure 5.2. Change in ROR crashes over time for situation where no paved shoulders are present versus having paved shoulders

5.6 Model for Single Vehicle Run-Off-Road Crashes

SVROR crashes were modeled assuming the distribution of the response variable is a mixture of Poisson and zeros (ZIP). The over-dispersion coefficient was estimated and removed since the over-dispersion is not significant. Estimated coefficients are shown in Table 5.5.

Table 5.5. Estimated coefficients for the SVROR crash model

Parameter	DF	Estimate	Standard Error	t value	P(T > |t|)	Notes
Intercept	1	0.215076	5.579220	0.04	0.9692	
Tot_RT_Shldr	1	-0.093168	0.005404	-17.24	<.0001	
Median	1	-0.422888	0.068072	-6.21	<.0001	
SpdLimit	1	0.014258	0.006823	2.09	0.0367	
after_trt_year	1	-0.015174	0.004143	-3.66	0.0002	
Year-1984	1	0.007368	0.002373	3.10	0.0019	
season1	1	0.305454	0.061813	4.94	<.0001	
season2	1	-0.032826	0.074419	-0.44	0.6591	
season3	1	-0.063991	0.074486	-0.86	0.3903	
pre_SVROR_SITE	1	0.085064	0.016607	5.12	<.0001	
LENGTH	1	0.261614	0.017135	15.27	<.0001	
$LENGTH^2$	1	-0.008882	0.001032	-8.61	<.0001	
DAYS	1	-0.163343	0.061103	-2.67	0.0075	
Parameter for zero model						
Intercept	1	-0.938593	0.080954	-11.59	<.0001	The probability that a record came from the zero model is about 0.28

As indicated in Table 5.5, the total amount of right shoulder available, presence of a divided median, speed limit and years after paved shoulders were installed were all statistically significant. Since the estimated probability of belonging to the zero model doesn't depends on other predictors. In this model, the effect of median can be estimated by:

$$E(Y|median=1, x_{other}) / E(Y|median=0, x_{others}) = \exp^{(-0.422888)} = 0.6552$$
.

As a result, around 35% fewer crashes are expected to result with a divided median versus having no divided median. It should be noted that presence of a median or not is correlated to number of lanes which was not included in the model.

The predictor "after_trt_year" = max(0, year – trt_year)*I(in treatment group) has a positive values only in the treatment groups. The "after_trt_year" explains the change of in estimated mean crashes after the treatment is applied. The coefficient of "after_trt_year"(-0.015174) explains the reduced trend after treatment.

If a treatment year of 1995 is assumed a plot showing the different is generated using the following:

For no treatment, the estimated change in crashes for each year is given by:

$$\exp^{(0.007368 * (\text{Year} - 1984))}$$

For years 1984 through 1995, the estimate is the same as for no treatment. From 1996 forward, the estimated change in crashes for each year is given by:

$$\exp^{(0.007368 * \{\text{Year} - 1984\} + -0.015174 * \{\text{Year} - \text{Treatment Year}\})}$$

The decrease in crashes over time is shown in Figure 5.3. As indicated, SVROR crashes per quarter are increasing over time independent of the treatment paved shoulders. However, once paved shoulders are added, the average number of SVROR crashes at sites where no treatment is present continue increasing over time. One year after treatment, the increase in SVROR crashes is 1.6% less than for no treatment. At 10 years, SVROR crashes are 16.4% lower for sections with paved shoulders than for sites with no treatment.

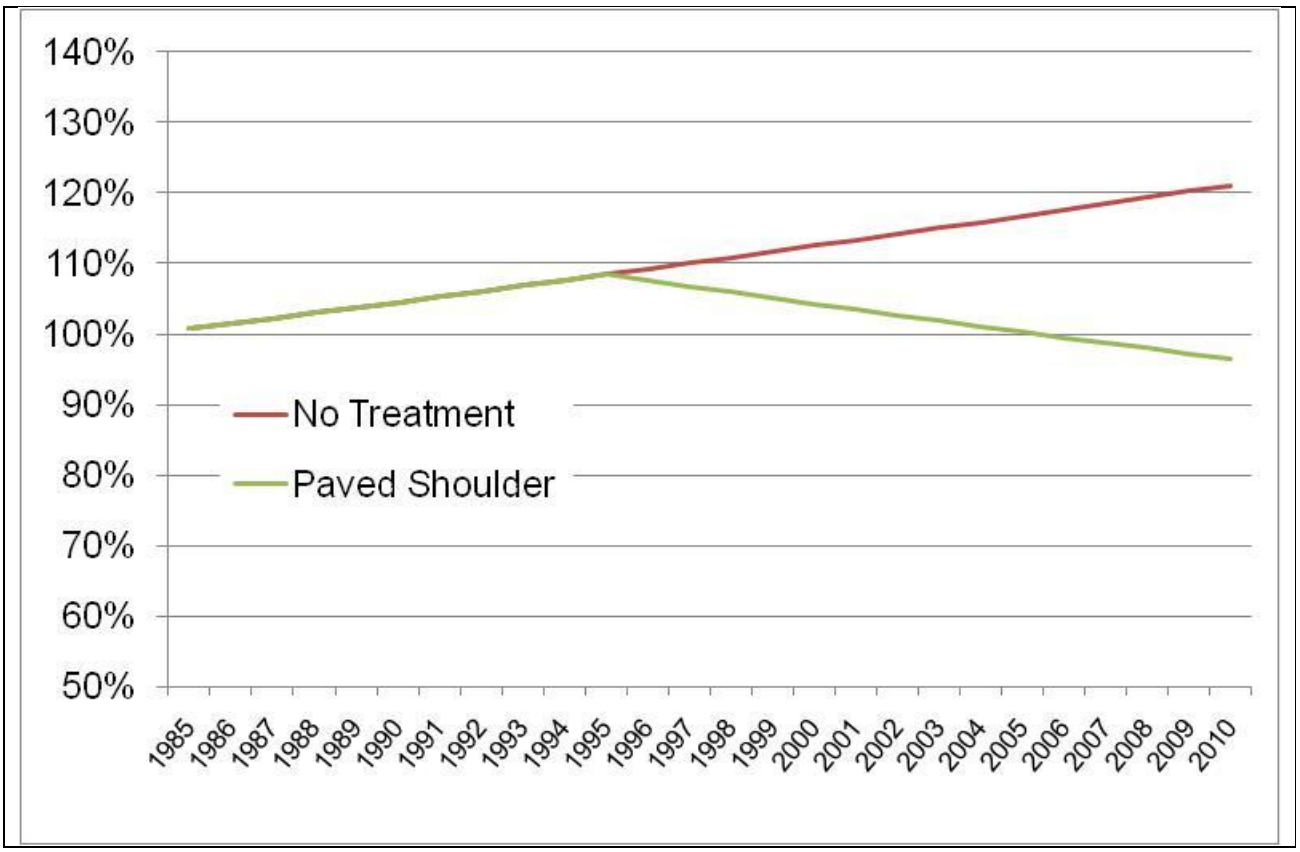


Figure 5.3. Change in SVROR crashes over time for situation where no paved shoulders are present versus having paved shoulders

6. SUMMARY

In 2004, Iowa adopted a paved shoulder policy for higher volume roads, but a broad diversity of paved shoulder types have been utilized for many years in the state. Because the benefits of paved shoulders have not been quantified, the Iowa DOT requested a study to analyze the safety performance of various paved shoulder designs on a wide spectrum of traffic and roadway types.

The research described in this report evaluated the effectiveness of paved shoulders. As part of the research, two surveys were conducted that assessed the opinions of field maintenance personnel and law enforcement personnel about the effectiveness of paved shoulders. Most maintenance personnel felt that paved shoulders led to reduced maintenance costs. Most officers felt that the shoulders reduced ROR crashes and improved safety for officers when they have to pull over for traffic stops.

This study also included a crash analysis for non-Interstate roadways in Iowa where paved shoulders have been installed. The team made site visits and collected roadway data for 256 roadway sections in Iowa. The majority was locations where paved shoulders had been installed, but a number of control sections were collected as well. Each test segment was reviewed, and the construction year for implementation of paved shoulders was determined. In some cases, the roadway segment could not be located in the GIMS database, and in other cases the construction year could not be determined. These sections were removed from further analysis. This resulted in a total of 220 sites analyzed, including77 control sections and 143 test sections. Sections included both two- and four-lane roadways. Four-lane roadways were both divided and undivided.

Generalized linear models were used to investigate the relationship between crash reduction and implementation of paved shoulders. The response variable was quarterly crash frequency. Traffic volume was modeled as offsets. Separate models were developed for total crashes, cross-centerline (CL) crashes, run-off-road (ROR) crashes which included all road departure crashes, and single vehicle run-off-road (SVROR) crashes which included only road departures involving a single vehicle. The model for each independent variable considered over-dispersion and excess zeroes.

The best fit model for total crashes per quarter was a zero inflated negative binomial model. Model results indicated that the total amount of right shoulder, presence of a median, speed limit, addition of a paved shoulder and years after addition of a paved shoulder were statistically significant. The effect of paved shoulder varied over time depending on the years after treatment. Since the effect of paved shoulder varies over time, one year after treatment, the decrease in total crashes for sections with paved shoulders for each quarter is 8.9% greater than for no treatment. At 10 years, the decrease is 15.9% greater.

A negative binominal model was the best fit model for cross-centerline crashes. The model indicates that crashes are negatively correlated to total feet of right shoulder and presence of median. The model indicated that the covariates used to model the effect of paved shoulders was not statistically significant. As a result, addition of paved shoulders had no impact on cross-centerline crashes.

ROR crashes were modeled assuming the distribution of the response variable is a mixture of Poisson and zeros (ZIP). The amount of total right shoulder available, presence of a divided median, speed limit and years after paved shoulders were installed were all statistically significant. The effect of paved shoulder on run-off-road crashes by quarter varied over time depending on the years after treatment. One year after treatment, the 1.3% fewer crashes are expected for sections with paved shoulder than for control sections. At 10 years, sites with paved shoulders have 13.5% fewer ROR crashes than control sites.

Single vehicle run-off-road crashes were modeled assuming the distribution of the response variable is a mixture of Poisson and zeros. The total amount of right shoulder available, presence of a divided median, speed limit and years after paved shoulders were installed were all statistically significant. The effect of paved shoulder on single vehicle run-off-road crashes by quarter varied over time depending on the years after treatment. One year after treatment, the SVROR crashes are 1.6% less than for no treatment. At 10 years, SVROR crashes are 16.4% lower for sections with paved shoulders than for sites with no treatment.

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APPENDIX A. DATA COLLECTION FORM

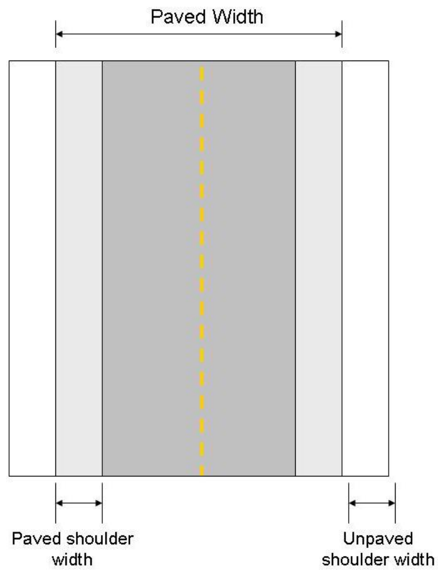
Paved Shoulder Data Collection Form

If this is a divided highway, note and do each direction separately

Date: ____________________ **County:** ____________________________________

Main St. (include gov and local names): ______________________________________
Begin cross-street: ____
End cross-street: ____
Note location on map for cross reference
Speed Limit: ___________ **Orientation:** N/S E/W
Sample -

Pavement Type:	Asphalt	Concrete	
Shoulder:	Fully Paved	Partially Paved	
Shoulder pavement type:	Asphalt	Concrete	
Unpaved Shoulder type:	Gravel	Earth	Mixed

West shoulder on N/S Road or North shoulder on E/W road		**East shoulder on N/S Road or South shoulder on E/W road**
Rumble strips None Milled Rolled **RS Location:** Edge of paved lane Edge of paved shoulder Dist from edge of paved shoulder _____________		**Rumble strips** None Milled Rolled **RS Location:** Edge of paved lane Edge of paved shoulder Dist from edge of paved shoulder ___________
Total paved width:		**Total paved width**:
Paved shoulder:		**Paved shoulder:**
Unpaved shoulder:		**Unpaved shoulder:**

Note if there is anything unusual about this roadway.

Note if paved driveway entrances exist or widening on curves:

Location and type of other lane widenings