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Evaluation of Pavement Markings on Low-Volume Rural Roadways in Iowa

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Abstract
Many rural roadways in Iowa have centerline and/or edgeline pavement markings. The current Manual on Uniform Traffic Control Devices (MUTCD), however, requires centerline and/or edgeline pavement markings only along streets and roadways with traffic volumes much greater than 400 vehicles per day (the volume-based definition of a low-volume roadway in the MUTCD). This project was initiated to gather and summarize information about the state of practice related to the installation and maintenance of pavement markings along low-volume rural roadways in Iowa. Additional information was also collected to provide more guidance in the pavement-marking decision-making process. The tasks completed include an examination and summary of past research, the collection of legal input related to the use of pavement markings in Iowa, and a survey of Iowa county engineers that focused on their current pavement-marking practices. A basic safety benefit-cost evaluation of pavementmarking applications was also performed. Overall, the literature on the effectiveness of pavement markings and their safety impacts is limited. A number of studies have been completed with varying levels of robustness and reliability in their results. The Highway Safety Manual includes crash modification factors for the installation of centerline markings that it indicates should be used with caution, and one for the installation of edgeline and centerline markings that equates to a 24 percent total serious and minor-injury crash reduction. A more recent study from Louisiana also found a 15 percent reduction in total crashes after the addition of edgelines. The legal input acquired as part of this project was generally common knowledge. It indicated that once a traffic control device has been installed, the jurisdiction must properly and adequately maintain it. The survey completed found that, of the great majority of the respondents (97 percent), painted centerline/no passing zones and edgelines on at least some of their paved low-volume rural roadways. A much smaller percentage took this approach, or just painted centerlines/no passing zones, along their seal-coated roadways. The basic cost-benefit evaluation found that the percentage of crash reduction needed from pavement markings to make them beneficial was very low (i.e., 5.1 percent, at most). Overall, it was concluded that pavement markings are widely used in Iowa along low-volume paved roadways and sometimes seal-coated roadways. In addition, there is a safety benefit to the installation of pavement markings. but the research into that impact is limited, particularly along low-volume roadways. It is recommended that further analysis be completed on potential pavement-marking safety impacts, that a pavement-marking database be developed, and that a committee be initiated to help develop policies related to pavement-marking removal.

Keywords
Center lines, Edge lines, Low volume roads, Highway safety, Pavement marking

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Evaluation of Pavement Markings on Low-Volume Rural Roadways in Iowa

Final Report
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16. Abstract

Many rural roadways in Iowa have centerline and/or edgeline pavement markings. The current Manual on Uniform Traffic Control Devices (MUTCD), however, requires centerline and/or edgeline pavement markings only along streets and roadways with traffic volumes much greater than 400 vehicles per day (the volume-based definition of a low-volume roadway in the MUTCD). This project was initiated to gather and summarize information about the state of practice related to the installation and maintenance of pavement markings along low-volume rural roadways in Iowa. Additional information was also collected to provide more guidance in the pavement-marking decision-making process. The tasks completed include an examination and summary of past research, the collection of legal input related to the use of pavement markings in Iowa, and a survey of Iowa county engineers that focused on their current pavement-marking practices. A basic safety benefit-cost evaluation of pavement-marking applications was also performed. Overall, the literature on the effectiveness of pavement markings and their safety impacts is limited. A number of studies have been completed with varying levels of robustness and reliability in their results. The Highway Safety Manual includes crash modification factors for the installation of centerline markings that it indicates should be used with caution, and one for the installation of edgeline and centerline markings that equates to a 24 percent total serious and minor-injury crash reduction. A more recent study from Louisiana also found a 15 percent reduction in total crashes after the addition of edgelines. The legal input acquired as part of this project was generally common knowledge. It indicated that once a traffic control device has been installed, the jurisdiction must properly and adequately maintain it. The survey completed found that, of the great majority of the respondents (97 percent), painted centerline/no passing zones and edgelines on at least some of their paved low-volume rural roadways. A much smaller percentage took this approach, or just painted centerlines/no passing zones, along their seal-coated roadways. The basic cost-benefit evaluation found that the percentage of crash reduction needed from pavement markings to make them beneficial was very low (i.e., 5.1 percent, at most). Overall, it was concluded that pavement markings are widely used in Iowa along low-volume paved roadways and sometimes seal-coated roadways. In addition, there is a safety benefit to the installation of pavement markings. but the research into that impact is limited, particularly along low-volume roadways. It is recommended that further analysis be completed on potential pavement-marking safety impacts, that a pavement-marking database be developed, and that a committee be initiated to help develop policies related to pavement-marking removal.

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EXECUTIVE SUMMARY

It has been common practice for most Iowa counties to enhance paved and/or seal-coated roadways with pavement markings (e.g., a yellow centerline and/or white edgelines). However, the current *Manual on Uniform Traffic Control Devices (MUTCD)* requires centerline and/or edgeline pavement markings only along streets and roadways with volumes much higher than 400 vehicles per day (vpd) (FHWA 2009). This project was initiated to provide local agencies with additional information that might be useful to their low-volume roadway pavement-marking decision-making.

The work included an investigation and summary of past pavement-marking research, a survey of Iowa county engineers that focused on their current pavement-marking practices, and a basic benefit-cost safety evaluation. The cost of installing and maintaining pavement markings was also documented, and an opinion on the legal implications related to pavement markings was obtained.

The *MUTCD* defines the standards used to install and maintain traffic control devices on all roadways open to public travel and applies to the determination and use of traffic control devices, including pavement markings, within the state of Iowa. Section 5E.02 of the *MUTCD* focuses on centerline pavement markings and states that they "…should be used on paved low-volume roads consistent with the principles of this Manual and with the policies and practices of the road agency and on the basis of either an engineering study or the application of engineering judgment." Section 5E.03 describes edgeline pavement-marking applications, stating they "…should be considered for use on paved low-volume roads based on engineering judgment or an engineering study."

Section 3B.01 discusses yellow centerline pavement markings and warrants, and states they "should also be placed on all rural arterials and collectors that have a traveled way of 18 feet or more in width and an [average daily traffic] ADT [volume] of 3,000 vehicles per day or greater." Centerline markings should also be placed on other traveled ways where an engineering study indicates such a need." Section 3B.07 discusses edgelines and states that they "shall be placed on rural arterials with a traveled way width of 20 feet or more and an ADT of 6,000 vpd."

This literature review of pavement markings examined the safety and safety-related impacts of centerlines and/or edgelines along roadways, with a specific focus on low-volume roadways. This literature included work from Kentucky, Louisiana, Pennsylvania, Texas and Virginia.

Several projects in Louisiana generally found that, on tangent roadway sections, drivers shifted toward the centerline during the day after edgelines were installed, but fewer crossed centerline. The Louisiana work also applied several safety analysis approaches, with the most robust finding a crash reduction of 15 percent when edgelines were added on narrow roadways (i.e., 22 feet or less) and benefit-cost ratios ranging from 75.56 to 117.58.

In Kentucky, the authors recommended that centerline and edgeline markings be used on roadways with a lane width of 9 feet, centerlines only for roadways with a lane width of 8 feet, and edgelines only for roadways narrower than 8 feet based on crash trend observations.

In Pennsylvania, yellow centerlines without an edgeline but in combination with features such as delineators or chevrons were found to improve driver recognition of roadway geometry.

In Texas, researchers found that the use of edgelines reduced crashes by up to 26 percent, but the greatest reductions were along roadways with lane widths of 9 to 10 feet. A follow-up with laboratory and field tests found that edgelines should be used on pavements with a width of at least 21 feet 9 inches, and applications on narrower pavements should be left to engineering judgement.

Finally, work in Virginia found that there was no statistically significant difference in the safety performance between low-volume narrow roadways (less than 3,000 vpd and 20 feet or narrower) with and without a centerline and/or edgeline.

Literature related to pavement-marking costs and removal indicated that approaches to application and maintenance of markings are based on condition inspections or a time-based interval (yearly, biyearly, remaining service life, etc.). Limited cost information available showed a general range of $0.06 to $0.15 per foot per marking for waterborne paint. Finally, commonly accepted removal methods in the literature included blasting, grinding, burning, chemicals, and masking.

A legal opinion on the use and maintenance of pavement markings was also requested as part of this project. It is included in its entirety in Appendix A of this report and the reader is encouraged to review it. The general conclusion of the opinion appears to be that, once a traffic control device is installed along a roadway, it must be properly maintained. The installation of a traffic control device, however, is different. The *MUTCD* is the accepted document for the application of traffic control devices as per Iowa Code, section 321.252 (State of Iowa Code 2015a).

A survey focused on pavement-marking use and maintenance was provided to all Iowa county engineers in 2014. A total of 37 counties responded. The survey results showed that 95 percent of the respondents (n= 35) paint centerline/no passing zones and edgelines on at least some of their paved low-volume rural roadways. Of these respondents, 21 percent (n = 7) stated that approximately 75 percent or more of their paved roadways are marked with both centerline/no passing zones and edgelines. These centerline/no passing-zone and edgeline markings are also typically replaced every two years.

Along seal-coated roads, the majority (76 percent, n = 28) of the respondents indicated that either pavement markings are not used along these type of roadways in their county, they don’t have any seal-coated roads that they maintain, or no response. Overall, 13 percent of the respondents stated that they use both centerline/no passing zone and edgeline markings on seal-coated roadways, and three percent responded that they use only painted centerline/no passing zones. The costs provided for the different types of markings in Iowa ranged from $3.25 to $14.00 per linear station (100 feet).

An exploratory analysis of pavement-marking benefits and costs was completed for a hypothetical one-mile segment of secondary roadway to determine the percent total crash reduction required to produce a benefit-cost ratio of 1.0. This calculation was completed for paved and seal-coated roadways with either centerline/no passing zone (NPZ) only or centerline/NPZ and edgeline marking configurations.

The total percent crash reductions calculated in this basic evaluation for centerline/NPZ pavement markings were about 0.42 and 1.9 percent for paved and seal-coated roadways, respectively. The percent crash reductions for the installation of centerline/NPZ and edgeline markings were 1.1 and 5.1 percent for paved and seal-coated roadways, respectively. However, these percentages are smaller than the reductions found in the literature. This evaluation shows the low level of total crash reductions that would be needed, on average, to make pavement markings beneficial.

Several conclusions and recommendations were developed based on the tasks completed as part of this project. Research on the safety and/or operational impacts of pavement markings was limited for low-volume roadways, and these projects had a wide range of robustness and results. Therefore, it is recommended that that safety impacts due to the installation of centerline/NPZ or centerline/NPZ and edgelines on both high-volume and low-volume roadways be further evaluated.

The development of a secondary roadway pavement-marking database is recommended to assist with the evaluation of pavement-marking installation, maintenance costs, and potential safety impacts.

The legal input provided to the project team about traffic control devices is generally common knowledge to Iowa counties and it is recommended that a committee be created to develop sample policies related to pavement-marking removal procedures. It is also recommended that this committee include a county attorney for the provision of legal advice on the sample policy.

It is recommended that information from research that has addressed stop sign removal and the input from this committee be used to develop policy content related to pavement-marking removal (e.g., a staged approach, including, among other things, the use of engineering judgement/study, informing the public, staged traffic control, and observation/monitoring).

CHAPTER 1. INTRODUCTION

Many Iowa local roadways are paved or hard surfaced. In fact, today Iowa has an extensive local system of paved rural roadways totaling about 18,000 miles and approximately 8,800 miles of those roadways serve low traffic volumes (i.e., 400 vehicles per day (vpd) or less) (Iowa DOT 2014). In addition, it is estimated that up to 1,100 miles of these low-volume county roadways have surface treatments, such as seal coating, to provide a dust-free driving surface.

It has been common practice for most Iowa counties to enhance paved and/or seal-coated roadways with pavement markings (e.g., a yellow centerline and/or white edgelines). However, the current *Manual on Uniform Traffic Control Devices (MUTCD)* requires centerline and/or edgeline pavement markings only along streets and roadways with volumes much higher than 400 vpd. This project was initiated to provide additional information about the state of practice related to the installation and maintenance of pavement markings along low-volume rural roadways in the state of Iowa. The results of the project should be of value to rural local transportation agencies.

Project Goal and Objective

The goal of this project was to investigate the state of the practice with respect to the use of pavement markings along low-volume rural roadways in Iowa. The project tasks included an investigation and summary of past pavement-marking research, a survey of Iowa county engineers that focused on their current pavement-marking practices, and a basic benefit-cost safety evaluation. The cost of installing and maintaining pavement markings and the legal implications related to pavement markings were also explored. The results of these tasks are summarized in this report. The objective of the project was to provide local agencies with additional information that might be useful to their low-volume roadway pavement marking decision-making.

Report Content

This report includes six chapters. The first chapter includes a general description of the issues addressed by this project, along with and its goal and objective. The second chapter is a summary of the relevant literature that focuses on pavement-marking use, maintenance, and/or removal in general, but along low-volume rural roadways more specifically. Chapter 3 is a summary of the legal input provided to the project team about traffic control devices in Iowa. The fourth chapter is a summary of the Iowa county pavement-marking practice survey, and chapter five includes a description of the approach taken and results of a basic safety benefit-cost evaluation. Chapter 6 includes the conclusions and recommendations developed from the completion of the tasks described in this report.

CHAPTER 2. LITERATURE SUMMARY

This chapter provides a summary of the literature related to the application, maintenance, removal, safety and/or operational impacts of pavement markings. First, the relevant sections of the *MUTCD*, the document that guides the application of pavement markings in Iowa, is summarized. This summary is then followed by some research-based application guidance. Then, several published research reports about pavement-marking use and/or its potential safety and/or operational impacts along low-volume roadways are described. This chapter concludes with a short summary of the literature on pavement-marking application, maintenance, removal, and costs.

MUTCD Pavement-Marking Application Information

The *MUTCD* defines the standards used to install and maintain traffic control devices on all roads open to public travel and applies to the determination and use of traffic control devices, including pavement markings, within the state of Iowa (State of Iowa Code 2015a). Parts 3 and 5 of the 2009 edition (with 2012 revisions) are the most relevant portions of the *MUTCD* to this research. Part 3 provides standards and guidance related to the installation and maintenance of pavement markings along roadways in Iowa, and Part 5 specifically focuses on similar information for low-volume roadways (the focus of this project). Both parts, however, indicate that pavement markings "…shall be retroreflective unless ambient illumination assures the markings are adequately visible" (FHWA 2009). In Part 3, the retroreflectivity requirement is for pavement markings that "…must be visible at night…" and those along interstates, but in Part 5 it is noted that all markings "…shall be visible at night and shall be retroreflective…" (FHWA 2009). Other standards, guidance, support, and option statements from Parts 5 and 3, individually, are summarized below.

Part 5: Traffic Control Devices for Low-Volume Roads

Part 5 of the *MUTCD* focuses on traffic control device standards, guidance, options, and support related to low-volume roadways. It defines a low-volume roadway, in general, as a paved or unpaved facility lying outside of built-up areas of cities, towns, and communities with an annual average daily traffic (ADT) volume of less than 400 vpd (FHWA 2009). It does, however, specifically exclude freeways, expressways, interchange ramps, freeway service roads, roadways on designated State highway systems, and residential streets neighborhoods from this definition (FHWA 2009).

Overall, the amount of information in Part 5 of the *MUTCD* that focuses on pavement markings is limited to Sections 5E.02 and 5E.03 (FHWA 2009). These two sections are described below. Much more information, however, is provided in Part 3 of the *MUTCD* and is described in the next section of this report. In fact, Part 5 generally refers the reader to the other parts of the manual for additional information because the remainder of the *MUTCD* also has provisions that apply to low-volume roadways.

Section 5E.02 of the *MUTCD* focuses on centerline pavement markings along low-volume roadways. It states that "…[c]enter line markings should be used on paved low-volume roads consistent with the principles of this Manual and with the policies and practices of the road agency and on the basis of either an engineering study or the application of engineering judgment" (FHWA 2009). It also notes that "[c]enter line markings may be placed on highways with or without edgeline markings…" and "…[w]here center line markings are installed, no-passing zone markings in compliance with Section 3B.02 shall also be installed" (FHWA 2009). Section 3B.02 simply indicates that "…where center line markings are installed, no-passing zones shall be established at vertical and horizontal curves and other locations where an engineering study indicates that passing must be prohibited because of inadequate sight distances or other special conditions" (FHWA 2009).

Section 5E.03 of the *MUTCD* describes some aspects of edgeline pavement-marking application along low-volume roadways. It notes that "[t]he purpose of edgeline markings is to delineate the left-hand or right-hand edge of the roadway…" and that they "…should be considered for use on paved low-volume roads based on engineering judgment or an engineering study" (FHWA 2009). They may be used on roadways with or without centerlines and "…may be placed on paved low-volume roads for roadway features such as horizontal curves, narrow bridges, pavement width transitions, curvilinear alignment, and at other locations based on engineering judgment or an engineering study" (FHWA 2009).

Part 3: Markings

Pavement-marking standards, guidance, options, and support are primarily provided in Part 3 of the *MUTCD*. The information in this portion of the *MUTCD*, however, applies to roadways with any traffic volume. As noted previously, Part 5 of the *MUTCD* focuses on low-volume roadways (i.e., 400 vpd or less), but the information provided is very limited and the user of the *MUTCD* is generally referred to Part 3 for additional guidance. The information relevant to this project that is in Part 3 is summarized below.

Centerlines and edgelines are defined in the *MUTCD* (FHWA 2009). It indicates that centerlines are used to delineate the separation of traffic lanes that have opposite directions of travel on a roadway and that edgelines are used to delineate the right or left edges of a roadway (FHWA 2009). In addition, it also notes that "…each standard marking shall be used only to convey the meaning prescribed for that marking…" and that those pavement markings "…that are no longer applicable for roadway conditions or restrictions and that might cause confusion for the road user shall be removed or obliterated to be unidentifiable as a marking as soon as practical" (FHWA 2009). The same section of the *MUTCD* also indicates that until the pavement marking is removed or obliterated it "…may be temporarily masked with tape that is approximately the same color as the pavement" (FHWA 2009).

Section 3B.01 of the *MUTCD* focuses on yellow centerline pavement markings and warrants (FHWA 2009). An application standard for centerlines is provided for urban arterials and collectors with certain characteristics and guidance has also been developed for centerline pavement markings along rural arterials or collectors. The rural roadway guidance statement is relevant to this project and includes the following:

- "Centerline markings should also be placed on all rural arterials and collectors that have a traveled way of 18 feet or more in width and an ADT of 3,000 vehicles per day or greater. Centerline markings should also be placed on other traveled ways where an engineering study indicates such a need" (FHWA 2009).

- "Engineering judgment should be used in determining whether to place centerline markings on traveled ways that are less than 16 feet wide because of the potential for traffic encroaching on the pavement edges, traffic being affected by parked vehicles, and traffic encroaching into the opposing traffic lane" (FHWA 2009).

It is important to note that most Iowa roadways are more than 18 feet in width, but a large percentage of roadways do not have 3,000 vpd in volume. The *MUTCD* also, of course, requires no-passing zones if centerline pavement markings are implemented. The information used to implement no passing zones is in Section 3B.02 (FHWA 2009).

Section 3B.07 of the *MUTCD* provides standards, guidance, options, and support information about the placement of edgelines (FHWA 2009). It indicates that edgelines shall be placed on rural arterials with a traveled way width of 20 feet or more and an ADT of 6,000 vpd. Additional guidance is also provided that edgelines should also be installed along roadways with a similar pavement width characteristic, but a traffic flow of only 3,000 vpd or more. In addition, it indicates that edgelines should also be installed where engineering judgment indicates a need, but not if engineering judgement or an engineering study indicates edgeline installation would reduce safety. Once again, as noted previously, the pavement width and volume characteristics of these standard and guidance statements generally have only limited applicability to county roadways in Iowa.

Other Pavement-Marking Application Guidance

Additional pavement-marking application guidance was also provided in several other documents that were reviewed as part of this project (Hawkins and Smadi 2010, Lund and Cox 2014, Sarasua et al. 2012, Migletz and Graham 2002). For example, Hawkins and Smadi provided guidance for the application of pavement markings based on remaining pavement service life (2010). For pavements along two-lane rural roads with speed limits less than 55 mph and less than 2 years of service life remaining, they recommended the use of waterborne markings. However, for rural two-lane pavements with 3 to 5 years of service life remaining, durable waterborne markings were recommended. Finally, for rural two lane pavements with more than 5 years of service life remaining, durable waterborne markings were also recommended, but with recessed dashed lines used to increase durability.

St. Louis County, Minnesota also has compiled a comprehensive pavement-marking management plan (Lund and Cox 2014). In general, the authors of the plan concluded that it was unrealistic to follow the pavement-marking installation warrants in the *MUTCD* because metrics such as traffic volumes may not necessarily reflect the function of the roadway (Lund and Cox 2014). It was concluded that engineering judgement would be employed and centerline markings would be maintained along all county roads. In addition, edgelines would be applied along all collectors and arterials as well as any local road included in the St. Louis County Road Safety Plan. It was also concluded that centerline markings should be replaced annually if the pavement surface rating was less than 3.3, and every 2 years if the rating was greater than 3.3. Edgeline markings were to be replaced every 3 years, regardless of the pavement surface rating at a site (Lund and Cox 2014).

A project by Sarasua et al. estimated the lifecycle of pavement markings along primary and secondary roads in South Carolina (2012). As part of their work, various recommendations were also made for the selection and application of pavement markings. In general, it was recommended that waterborne paints be used along roadways with traffic volumes of less than 1,000 vehicles per day (Sarasua et al. 2012). In addition, the estimated life (based on traffic volumes, surface type, and pavement-marking material) of waterborne paint yellow centerlines was 2 years, while similarly painted white edgelines had a life of 5 years. It was also noted that the installation of pavement markings should include proper surface preparation, specifically cleaning/brooming and removal of existing pavement markings in poor condition, and an absence of surface moisture (Sarasua et al. 2012).

Finally, *NCHRP Synthesis 306: Long-Term Pavement Marking Practices: A Synthesis of Highway Practice* highlighted some long-term pavement-marking practices and focused on best practices for managing pavement-marking systems (Migletz and Graham 2002). The agencies surveyed as part of the synthesis indicated that pavement markings were generally renewed after a field inspection, the judgment of maintenance personnel, or based on a regular schedule. Agencies only indicated markings were removed as part of a renewal process or when traffic patterns changed as part of construction activities. Factors employed in determining the type of material to use for pavement markings varied, but included the type of line being installed, the pavement surface and its condition, traffic volume, the functional classification of the roadway, remaining pavement surface life, snow removal, the brightness benefit factor, and vehicle speeds at the site (Migletz and Graham 2002).

Pavement-Marking Safety-Related Impacts

The focus of the literature review completed as part of this project was research projects that specifically focused on the potential safety impacts due to the installation of typical pavement markings along low-volume roadways. The summary below includes a short description of the pavement-marking crash modification factors (CMFs) included in the *Highway Safety Manual (HSM*) (AASHTO 2010), but primarily focuses on the results from studies that evaluated the potential safety-related impacts connected to the installation of typical edgelines. These studies were completed in Louisiana, Kentucky, Texas and Virginia (Sun and Tekell 2005, Sun and Das 2012, Sun and Das 2014, Agent and Green 2008, Tsyganov et al. 2006, Tsyganov et al. 2005, Dougald et al. 2013, Kweon et al. 2015). No studies (other than the one noted below from the

HSM) were found that focused on the potential safety-related impacts due to the installation of the centerline markings.

Highway Safety Manual CMFs

The *HSM* includes CMFs for the installation of edgelines, centerline markings, and the combination of centerline markings and edgelines (AASHTO 2010). The CMFs in the *HSM* for edgelines (4 to 8 inches wide) installed along two-lane rural highways range from 0.97 to 1.05 (AASHTO 2010). However, it is noted in the *HSM* that these CMFs should be used with caution because their standard error includes 1.0 (i.e., the expected impact could be negative, positive, or 0) (AASHTO 2010). Similarly, the CMFs for the installation of centerline pavement markings were 0.99 and 1.01 for serious or minor injury and propertydamage only (PDO) crashes, respectively (AASHTO 2010). The *HSM* also noted that these CMFs should be used with caution for the same reasons as those described above (AASHTO 2010). The CMF in the *HSM* for the installation of both centerline and edgelines, on the other hand, is 0.74 (for serious and minor injury crashes). This CMF is equivalent to a serious and minor injury crash reduction of 26 percent and had a small enough standard error that no cautionary notes about its use were needed (AASHTO 2010). It should be noted, also, that there are additional CMFs and crash reduction percentages in the Federal Highway Administration (FHWA) CMF Clearinghouse for edgeline installation. It does not appear, however, that any of these studies were done along low-volume roadways.

Louisiana Studies

Sun et al. have completed several projects that focused on the potential operational and/or safety impacts of edgeline installation (Sun and Tekell 2005, Sun and Das 2012, Sun and Das 2014). The first project was completed in 2005 and focused on the operational impacts of edgelines and is discussed in another section of this chapter. In 2012, however, Sun et al. continued the 2005 study and attempted to quantitatively determine if there was a relationship between the addition of edgelines and crash frequencies (Sun and Das 2012). The study sites used in this research were narrow (i.e., a pavement width of less than 22 feet) two-lane rural roadway segments on the Louisiana Department of Transportation and Development (DOTD) highway system. They were located throughout the state (i.e., in each of the nine Louisiana DOTD districts). First, the researchers identified two-lane roadway segments in the database and then a combination of crash frequency and rates from 2000 to 2007 were used to screen these segments. No documentation was provided about how this combination was applied, but the result of the initial screening was 86 different roadway segments. These 86 roadway segments were then screened again through the review of roadway images. Any that already had edgelines, were not two-lane roadways, were on bridges, or had curbs were screened out. The secondary screening resulted in the selection of 30 sites for edgeline implementation and analysis. The number of segments in each Louisiana DOTD district ranged from one to nine, and consideration of the report appendix material revealed that the length of the segments appeared to range from 0.04 to 10.91 miles. No additional summaries of the distribution of the roadway segment-length database were provided (Sun and Das 2012).

The edgelines in the Louisiana study were added in 2008 to each of the 30 study sites. Then, annual crash frequency data from 2005 to 2007 (the before period) and from 2009 (the after period) were collected. No documentation was provided in the report about the type or severity of crashes in the data collected, but it was assumed that the analysis included all crash types and severities. These crash data were evaluated through three methods. The researchers defined the first method as a naïve before and after approach. Then, they also applied what they labeled a "naïve before-and-after analysis with treatment for different duration of time period" (Sun and Das 2012). Third, the researchers completed an "improved prediction method with traffic change" (Sun and Das 2012). In general, the last two approaches appeared to be expansions of the naïve before-and-after study initially completed.

The naïve before-and-after analysis completed by the researchers provided results that were labeled "somewhat confidently detectable," "confidently detectable," and "virtually confidently detectable." These categories, however, were not defined and the equation used to make these calculations appears to assume a normality in the crash data (although this assumption was not documented). This assumption, along with several other commonly accepted weaknesses of the naïve before-and-after analysis approach, may limit the statistical robustness and value of its results. Therefore, although the researchers do conclude that the difference in crashes was "somewhat confidently detectable," the conclusion from this review of the documentation is that this result holds little value.

The second method applied to the crash data was what the researchers called a "naïve before-and-after analysis with treatment for different durations of time period" (Sun and Das 2012). They indicate that this approach was proposed by Ezra Hauer in his book on observational studies (Hauer 1997). In this approach, they account for different before-and-after time periods by a simple proportionality approach to annual crash frequencies. The researchers conclude, based on their data and calculations, that the approach produces a CMF estimate of 0.90 with a standard deviation of 0.056. This approach appears to be an expansion of the naïve before-and-after analysis and likely uses equations based on a series of data-related assumptions that are not documented or verified in the project report. The significance or value of these calculations and the results provided, therefore, is difficult to discern. These results should be used with caution.

The third method applied to the crash data in the Louisiana study was labeled an "improved prediction method with traffic change" by the researchers (Sun and Das 2012). The researchers indicated that it is an attempt at an unbiased observational before-and-after study. They show and apply a series of steps and equations that they used to compare the predicted level of crashes with and without the edgeline implementation. The equations are similar to those used in the second method described above, but ADT and the different before-and-after data time period durations appear to be taken into account. The application also uses an equation from a book by Hauer to estimate the percent coefficient of variation in the data, but this equation is actually from a then unpublished document in 1997 (Hauer 1997, Vallurupalli 1997). No additional explanation is provided about this equation or the validity of its use in this effort. Overall, once again, the documentation of the process appears to be limited with regard to the details of the application. The conclusion of the researchers, however, is that the methodology followed allows them to estimate a CMF of 0.78 with a standard deviation of 0.144 (Sun and Das 2012). They also concluded that this methodology produced their most reliable results (Sun and Das 2012).

Unfortunately, the ranking for this CMF in the CMF Clearinghouse is only two of five stars (i.e., 3 to 6 points on a 14-point scale) and it should be used with caution for various reasons. The researchers also adjusted their answer for the overall trend in crashes during the time periods considered. This adjustment led to a proposed CMF of 0.83 with the same standard deviation, but the validity of this type of adjustment is unknown and the two standard deviations range of this result also includes 1.0 (i.e., the expected impact could be negative, positive, or 0).

The safety analysis was extended even further by Sun and Das (Sun and Das 2014, Sun et al. 2014). They considered two additional years of crash data and used the empirical Bayes (EB) method of analysis (Sun and Das 2014, Sun et al. 2014). This type of analysis is much more specific and accounts for several of the weaknesses in more basic approaches. It is statistically defensible and commonly accepted. In general, the process combines observed crash frequencies and safety performance function (SPF) predictions (based on generalized linear models) to determine the expected crash frequency if the improvement was not implemented. Comparisons are then made to more specifically estimate the expected impact of the improvement. In this case, the SPF used by the researchers came from the *HSM* and they calibrated SPFs for each of the before-and-after years included in their database (i.e., 2005 through 2007 in before time period and 2009 through 2011 in the after time period) (Sun and Das 2014, Sun et al. 2014).

Based on their application of the EB method, the researchers concluded that placing edgeline markings on narrow roadways (i.e., widths between 20 and 22 feet) could reduce crashes (Sun and Das 2014, Sun et al. 2014). The EB analysis results produced a total crashes CMF of 0.84 with a standard deviation of 0.0397 (Sun and Das 2014, Sun et al. 2014). The researchers then considered the background growth or reduction in crashes along roadways with similar widths in Louisiana. They concluded that crashes along these roadways had decreased by approximately 1.0 percent and subsequently changed their recommended CMF for total crashes to 0.85 (with the same standard deviation). This type of adjustment, however, does not appear to be typical in previous EB analysis efforts and its validity is unknown. The result from this study is listed in the CMF Clearinghouse and ranked with three of five stars. The application of the result and its standard deviation indicate a likely reduction of approximately 15 percent in total crashes if edgelines are applied.

Kentucky Study

Documentation of a 2008 study in Kentucky by Agent and Green was also reviewed (Agent and Green 2008). This study considered crash patterns along two-lane rural roadways, and two of the characteristics considered were lane and roadway width (Agent and Green 2008). In fact, the study generally focused on segments with estimated lane widths of 9.5 feet or less (Agent and Green 2008). Overall, a total of 170 miles of roadway with this characteristic appeared to have been found and 3 years of crash data (2004 to 2006) were used (Agent and Green 2008). The study considered single-vehicle, rear-end, angle, opposite-direction side-swipe, and head-on crash types.

A summary of the data collected for the Kentucky study showed that, as lane width decreased, the number of crashes increased (Agent and Green 2008). In fact, when lane widths were 7 feet, the number of crashes found were approximately twice that of roadways with a lane width of 12 feet (Agent and Green 2008). The analysis also revealed that roadways with narrow lanes (i.e., widths of seven to nine feet) had approximately twice the percentage of single vehicle crashes than those with wider lanes, while roads with wider lanes had the highest percentages of rear-end, angle, and same-direction crashes (Agent and Green 2008). The researchers also specifically focused on 5.3 miles of very narrow (i.e., 15- to 16-foot) two-lane rural roadways that had edgelines but no centerline. This crash analysis compared 5 years of crash data before the edgelines were installed to 1 year of data after the installation. Based on this naïve before-and-after comparison, the researchers concluded that edgelines could be implemented without centerlines along these type of narrow rural roadways without increasing single-vehicle, opposite-direction head-on, or side-swipe crashes (Agent and Green 2008). The weaknesses to this type of naïve before-and-after comparison, however, were described previously.

Overall, the researchers recommended centerline and edgeline markings for roadways with lane widths of 9 feet but only centerlines for roadways with lane widths of 8 feet (Agent and Green 2008). In addition, for lane widths less than 8 feet, only edgeline markings were recommended (Agent and Green 2008). They also recommended 1- to 5-foot paved shoulders for all roadway lane widths (Agent and Green 2008).

Texas Study

Documentation for a pavement-marking study completed in Texas was also reviewed (Tsyganov et al. 2006). This study summarized crash data from two-lane roadway segments with and without edgelines (Tsyganov et al. 2006). A basic crash comparison was completed that considered pavement-marking type and dimensions, lane width, shoulder width, traffic volume, the number of horizontal curves per mile, and their horizontal curve radii (Tsyganov et al. 2006). The summary below describes a portion of the project results.

The evaluation completed as part of this study considered crash data from 1998 through 2001 from segments that were a minimum of 3 miles in length (Tsyganov et al. 2006). Data from 2,822 segments that comprised 12,875 miles of roadway were summarized, but only those segments with more than one crash were used. Edgelines were present on only 974 of the segments (and the total mileage of these segments was not specified). The final crash database included 9,774 crashes. Overall, it was found that roadways without edgelines had a crash rate of 1.63 crashes per million vehicle-miles traveled (M VMT), but those with edgelines had a rate of 1.50 crashes per M VMT (Tsyganov et al. 2006). The project results also indicated that crashes on highways without edgelines were more concentrated than those with edgelines.

The potential impact of lane widths, horizontal curves, and crash type related to edgelines were also investigated (Tsyganov et al. 2006). The lane widths examined in this research project ranged from 9 to 11 feet and crash rates decreased as lane width increased. The segments with 11-foot lane widths and edgelines had the lowest crash rates. Run-off-the-road (ROTR) crashes were also found to be 11 percent higher along roadway segments with 9-foot lanes and no edgelines in comparison to those that had edgelines. In addition, ROTR crashes were 53.7

percent of all crashes on roadway segments with edgelines, but 64.9 percent on roadway segments without edgeline markings (Tsyganov et al. 2006).

Finally, the crash summary and comparison completed as part of this project also showed that horizontal curves with edgelines had a crash frequency that was 26 percent lower than those without edgelines (Tsyganov et al. 2006). In addition, when lane width was considered with regard to curvature, the researchers found a greater number of crashes for all lane widths without edgelines than those with edgelines (the largest difference was for 9-foot lane widths) (Tsyganov et al. 2006).

Virginia Study

Finally, the documentation from a pavement-marking safety study in Virginia was reviewed (Dougald et al. 2013, Kweon et al. 2015). More specifically, Dougald et al. examined crash data along two-lane roadways with traffic volumes of 3,000 vpd or less and pavement widths of 20 feet or less. They specifically noted that current maintenance demands and limited funds had prompted their investigation of what the potential safety benefits were from the use of pavement markings along low-volume roads. A similar question prompted this work in Iowa.

The project in Virginia used 5 years of crash data (i.e., 2004 through 2008) from 4,797 roadway segments to develop safety performance functions (SPFs) that included the type of pavement marking present (Dougald et al. 2013, Kweon et al. 2015). The four pavement-marking conditions considered were no markings, centerline-only markings, edgeline markings only, and the use of both centerline and edgeline markings. The SPF development used a negative binomial regression model and included variables for pavement width, AADT, and segment length. Overall, 12 different SPFs were created. One SPF for each of the four types of pavement markings present along three different pavement widths (i.e., 16-, 18-, and 20-foot) (Dougald et al. 2013, Kweon et al. 2015).

The models for each of the pavement widths produced interesting results (Dougald et al. 2013, Kweon et al. 2015). For 16-foot pavements, the prediction curves indicated that the expected number of crashes with no markings was lower than the model for the combined pavement markings or the use of only a centerline (Dougald et al. 2013, Kweon et al. 2015). For 18-foot pavements, however, the prediction curves for roadways with no markings and those with a centerline were similar to one another. The prediction curve for roadways with both markings, on the other hand, would produce expected crashes above the other two for AADTs below 1,000 vpd, and below them for AADTs greater than 1,000 vpd. In other words, for 18-foot pavements, they were predicting that segments with both markings would have more expected crashes for AADTs less than 1,000 vpd and fewer crashes for AADTs above 1,000 vpd. Finally, for 20-foot pavements, the sites with no marking were predicted to have fewer crashes than those with both pavement markings and centerline only markings at all AADT levels (Dougald et al. 2013, Kweon et al. 2015).

The researchers, however, provided one caveat to the results described above. They noted that the prediction models were based on data from crashes that considered all crash types. But all crash types are not generally related to the presence or absence of pavement markings. For example, an animal-vehicle crash is not influenced by pavement markings, but such crashes were present in the crash dataset. To address this, the researchers repeated the analysis discussed above for four different crash datasets. The additional datasets excluded various types of crashes (e.g., collisions with a train, wild animals, or pedestrians, those involving vehicles backing, unclassified crash types, rear-end crashes, and angle crashes). One dataset also only included roadway departure crashes. Overall, the results generated by the use of these different crash datasets produced the same observations and conclusions that were made with the entire crash dataset. In general, based on limited analysis, this research found no statistically significant difference in the safety performance between low-volume narrow roads (less than 3,000 vpd and 20 feet or narrower) with and without a centerline and/or edgeline.

Pavement-Marking Operational Impacts

In addition to examining the safety impacts of pavement markings, some of the published evaluations that were reviewed also considered the potential operational impacts of pavement markings (Sun and Tekell 2005, Tsyganov et al. 2005). The summary below includes a description of the study results from Louisiana, Pennsylvania, and Texas (Sun and Tekell 2005, Tsyganov et al. 2005, Pietrucha et al. 1996). The Louisiana and Texas studies primarily focused on vehicle placement related to pavement markings (Sun and Tekell 2005, Tsyganov et al. 2005). The Pennsylvania study, on the other hand, examined the impacts of delineation on older drivers (Pietrucha et al. 1996).

Louisiana Study

In one of their studies, Sun et al. focused on how the addition of edgelines along rural two-lane roadways could impact operator behavior and possibly affect highway safety (Sun and Tekell 2005). The hypothesis of the researchers was that the addition of edgelines might force drivers to position their vehicles closer to the centerline and possibly increase the risk of head on and sideswipe collisions.

The study sites for this project consisted of three horizontal curves and seven tangent, two-lane roadway segments along the Louisiana state highway system. The pavement widths at the sites considered ranged from 18.5 feet to 21 feet, and they all had posted speed limits of 55 mph (although two had posted advisory speeds of 45 mph).

The focus of this study was the vehicle position after pavement-marking edgelines were implemented (Sun and Tekell 2005). Therefore, vehicle position data (along with ADT) and speeds were collected using pneumatic road tubes for a 24-hour time period before and after the edgeline markings were applied at all 10 study sites. It is unknown, however, if the 24-hour data collection time periods were consistent at each site with regard to the number of days that passed before or after the implementation. Overall, four different vehicle position categories were defined and summarized for the 10 study sites. These categories included the following:

- Vehicles operating 0 to 1 foot from roadway edge
- Vehicles operating 1 to 2 feet from roadway edge
- Vehicles operating 2 feet from road edge, but not crossing the centerline
- Vehicles operating over the centerline

Unfortunately, the summary document explaining the data collected for this project did not appear to include an explanation of which vehicle position category was used if vehicles were exactly one or two feet from the roadway edge.

The researchers summarized the data they collected. First, the ADT and vehicle speed data were summarized by study site before and after the edgeline implementation. In general, the researchers believed that the changes in ADT and average vehicle speeds before and after the edgeline implementation were unusual. Then, the percentage of vehicles in each vehicle position category (previously described) and average speeds before and after the edgeline implementation were plotted for the horizontal curve sites (number equals 3/n = 3) and tangent study sites (n = 7) for three different time periods: the entire 24 hour collection period, daytime hours (i.e., 7 a.m. to 5 p.m.), and nighttime hours (i.e., 7 p.m. to 5 a.m.). Finally, the tangent study site data were further categorized for various roadway geometric and traffic characteristics. These characteristics included the following:

- Roadway widths ≤ 20 feet and > 20 feet
- Calculated average speeds ≤ 50 mph and > 50 mph
- Percentage of heavy vehicle ≤ 10 percent and > 10 percent
- Roadways with and without edge drops, and
- Good and poor pavement condition

Unfortunately, the report summarizing this data collection at no point indicated the size of the database at each study site for vehicle placement, volume, or speed before and after the implementation of edgeline. The data size, therefore, within each of the categorized summaries and comparisons completed is unknown. It is assumed in the summary of this work below, however, that the sample size was large enough to make the conclusions described.

Overall, the researchers concluded that the lateral position of vehicles within the lane at tangent-section study sites, during the day, shifted toward the centerline after the edgelines were implemented (Sun and Tekell 2005). However, there was also a decrease in the number of vehicles that crossed the centerline. At night, drivers positioned their vehicles in more of a central location within the lane than what they did during the daytime. At the curve study sites, data were collected along the outside lane at two locations and along the inside lane at the third location. The data from the inside lane showed that, after the edgelines were installed, there was a decrease in the percentage of vehicles driving in the 0- to 1-foot from the roadway edge and the 2-foot to centerline vehicle-position categories. In addition, there was an increase in vehicles driving 1 to 2 feet from the roadway edge. The data also showed a marginal increase in the number of drivers crossing over the centerline and speeds decreased slightly. In the outer lane, drivers crossed over the centerline before and after the edgelines were applied, but there was an increase in this occurrence after the edgelines were installed. Speeds also increased in the outer lane after the edgelines were added. In general, drivers appeared to move closer to the centerline in the outside lane, but they also remained close to the roadway edge along the inside lane after the edgelines were installed.

The researchers also summarized the vehicle position data from the tangent study sites (n = 7) by various roadway geometric and traffic characteristics (see the previous discussion) for the 24-hour period, daytime hours, and nighttime hours (Sun and Tekell 2005). First, the data were summarized for study sites with roadway widths less than or equal to 20 feet and greater than 20 feet. In general, the researchers concluded that the data showed a decrease, after the edgelines were added, in the percentage of vehicles close to the edgelines and those crossing the centerline at the study sites that were 20 feet wide or narrower. However, when the roadway width was greater than 20 feet, the percentage of vehicles passing within 0 to 1 foot of both the roadway edge and centerline decreased, and the percentage of vehicles passing over the centerline increased. These results appear to contradict each other, but no explanation was provided by the researchers. The patterns found in the data for the 24-hour collection time period appeared to be similar to that collected during the daytime hours, but the data from the nighttime hours was slightly different. At night, the differences in the percentage of vehicles traveling between 2 feet from the edgeline and the centerline seemed to increase or remain the same and the increase in centerline crossings along the narrower pavement widths seems to be less. The general conclusion of the researchers was that the installation of the edgeline on narrower roadways decreased vehicles near the edgeline and crossing over the centerline. In addition, along the wider roadways, the percentage of vehicles near the edgeline also decreased and those going over the centerline increased. No explanation of why this might be occurring was offered.

The researchers also summarized the vehicle position data along the tangents for the study sites with a calculated average operating speed of less than or equal to 50 mph (n = three study sites) and more than 50 mph (n = four study sites) (Sun and Tekell 2005). For the 24-hour period, at sites with a recorded average operating speed of less than or equal to 50 mph the percentage of vehicles passing over the centerline increased slightly after the edgelines were added, but the percentage of vehicles in the other categories decreased. Along the study segments that had a recorded average operating speed of 50 mph or greater the percentage of vehicles passing 0 to 1 feet from the roadway edge and over the centerline decreased, but those positioned 2 feet from the edgeline to the centerline increased. Similar to the results for the pavement width, a few differences were also found in the vehicle positions during the daytime and nighttime data collection periods. In both cases, the percentage of vehicles 0 to 1 foot from the edgeline decreased after the edgeline implementation, but the percentage of vehicles in the 1- to 2-foot range shifted in the daytime hours at the slower speed locations and in the nighttime hours at the higher speed locations.

The researchers also considered the differences in the percentage of vehicles within each position category for heavy vehicle levels above and below 10 percent (Sun and Tekell 2005). The heavy vehicle evaluation summary documentation, unfortunately, doesn't appear to match with the plots provided in the report. A review of the 24-hour data collection time period plots, before and after the addition of edgelines, appears to indicate a reduction in vehicles traveling close to the edgeline (i.e., 0 to 1 feet and 1 to 2 feet) and passing over the centerline when the percentage of heavy vehicles is less than or equal to 10 percent (and similar results were found in the daytime). At nighttime, however, there was an increase in vehicles 1 to 2 feet from the edgeline and a decrease from 2 feet to the centerline. At the study sites (n = 5) with a heavy-vehicle percentage greater than 10 percent, the changes in the percentage of vehicles in each category were similar, but those crossing the centerline increased (and similar patterns were found during the nighttime) after the edgelines were added. But, during the daytime, the percentage of vehicles 1 to 2 feet from the edgeline increased after the pavement marking was added, but the percentage in the 2-feet-to-centerline category decreased (which was opposite of the 24-hour period data). The researchers concluded that the data showed vehicles were passing closer to the edgeline when heavy vehicles were present, but that the heavy vehicle traffic also influenced the percentage passing over the centerline. No indication was given in the project study documentation, however, that only data connected to vehicles opposing heavy vehicles were considered.

Pavement edge and condition were also considered with respect to vehicle position before and after the implementation of edgelines (Sun and Tekell 2005). The researchers concluded that whether an edge drop-off was present or not, the percentage of vehicles in the 0- to 1-foot range still decreased with the addition of an edgeline. In addition, for the sites with edge drops, the percentage of vehicles 1 to 2 feet from the edgeline and passing over the centerline decreased, but the percentage of vehicles 2 feet from the edgeline to the centerline increased (and a similar pattern was also found in the data from the daytime and nighttime hours, but the percentage of vehicles in the 1- to 2-foot category increased at night). For study sites without an edge drop-off the percentage of vehicles 1 to 2 feet from the edgeline and the number of vehicles over the centerline increased, but the percentage of vehicles 2 feet from the edgeline to the centerline decreased (and a similar pattern was found during the daytime and nighttime hours). For the pavement condition evaluation, the data generally showed that the addition of edgelines on good pavement were related to a decrease in the percentage of vehicles crossing the centerline, within 0 to 1 feet from roadway edge, and 1 to 2 feet from the edge. Vehicles traveling 2 feet from roadway edge to the centerline, however, increased (and similar patterns were found in the data from the daytime and nighttime hours, but the percentage of vehicles traveling 1 to 2 feet from the edgeline increased at night). Poor pavement conditions appeared to result in an increase in the number of vehicles crossing over the centerline, but the percentage of vehicles in the other categories decreased (and similar results were found in the nighttime data, but the percentage of vehicles traveling 1 to 2 feet from the edgeline increased during the day).

Finally, the researchers also checked the time at which vehicles activated the data collection devices and considered situations where vehicles were facing high opposing traffic (Sun and Tekell 2005). These situations were defined by 15-minute-period binned volume data to determine higher-volume interaction periods. The approach used is questionable because it doesn’t appear to attempt to determine pairs of interacting vehicles and use that as a dataset. However, using the definition above for time periods of higher interaction, the general conclusion of the researchers was that vehicles operated within their travel lane and did not appear to move closer to the roadway edge or the centerline after the edgeline was installed.

Overall, the general conclusions of the researchers were that the addition of edgelines seemed to result in vehicles being more centrally located within their lane at night, but that the edgelines resulted in vehicles operating further away from the roadway edge (Sun and Tekell 2005). The researchers also concluded that the magnitude of the shift from the edgeline also appeared to be influenced by roadway width, operating speed, time of day, frequency of heavy vehicles, pavement condition, roadway alignment, and traffic from the opposite direction (Sun and Tekell 2005). In addition, the researchers believed that the addition of the edgelines didn't appear to have an impact on vehicle operating speeds. No conclusions were made about the horizontal curve sites. However, the researchers did generally conclude that the addition of the edgelines had a positive impact on two lane roadways (with an emphasis at night). They recommended that a safety analysis be done (which was discussed previously in this report) (Sun and Tekell 2005).

Unfortunately, the review of this study document showed that it only included a summary of the data collected with a comparison of vehicle placement under different scenarios. No statistical analysis appears to have been completed to actually determine the inter-correlations or influence of the categorical variables before and after the addition of a roadway edgeline. The patterns described within their categorizations are sometimes interesting, but also often difficult to explain. This confusion is likely due to the inability to control for the interactions between the roadway characteristics and vehicle positioning variables being considered. Vehicles traveling in a more centralized manner in the lane is a potential positive safety impact, but the reader is advised to use the results, as they are described here, with some caution and an understanding of its limitations.

Texas Study

In a follow-up study to some of their earlier work (previously described in this report), Tsyganov et al. also performed a before and after comparison of driver behavior and reactions to the addition of edgelines along three rural two-lane roadways in Texas (2005). Before and after speed and lateral position data for the sites were collected using an unmarked vehicle and a video camera parked off the roadway in an adjacent driveway. In addition, a test vehicle with sensors and cameras was driven along the roadway segments while the physical response of the drivers was measured with sensors (i.e., electrocardiograms). Finally, 77 subjects in a laboratory were also shown pictures of a black background with different horizontal curve-marking layouts (i.e., centerline only and centerlines with edgelines) and asked to rank each horizontal curve as smooth, moderate or sharp (Tsyganov et al. 2005). Subjects were also shown a video recorded from a moving vehicle at night before and after edgeline installation to investigate the effects of edgeline discontinuities on intersection recognition within a horizontal curve (Tsyganov et al. 2005).

The results of the three tests described above revealed several interesting edgeline impacts (Tsyganov et al. 2005). The before and after field studies indicated that drivers increased their speeds after the edgelines were installed (Tsyganov et al. 2005). However, while these increases averaged approximately 5 miles per hour, they were determined to not be statistically significant (Tsyganov et al. 2005). The lateral position measurements also indicated that the addition of edgelines had no significant vehicle positioning impact along the narrowest roadway width (i.e., 18 feet), but an average shift of 1.5 feet toward the edgeline occurred along the wider (i.e., 20- to 22-foot) roadway study sites. The data collected with the test drivers and vehicles were slightly different than that described above, but no consistent pattern of lateral vehicle movement due to the addition of the edgelines was found. It was found, however, that the emotional tension (measured by the electrocardiogram) of the drivers fell by 6 percent and heart rates were reduced by 12 percent after the edgelines were installed (Tsyganov et al. 2005). Finally, the laboratory study showed that the addition of edgelines significantly improved horizontal curve and intersection recognition (Tsyganov et al. 2005).

In general, the Texas researchers concluded that edgelines should be installed on pavements with a width of at least 21 feet 9 inches (Tsyganov et al. 2005). The rationale behind this precise width, however, was not provided. It appeared to be based, in part, on considerations of the collective width that centerline and edgeline markings would require on the pavement surface (Tsyganov et al. 2005). For narrower roadways, they recommended the use of engineering judgement (Tsyganov et al. 2005).

Pennsylvania Study

Documentation that summarized the results from a project that focused on how different pavement markings and delineation devices could be used to improve the performance of older drivers was reviewed as part of this study (Pietrucha et al. 1996). The study began with a summary that focused on typical older-driver operating performance deficiencies, and the results of this summary were used to select a series of potential treatments. Overall, a total of 25 treatments were selected for evaluation with a driving simulator (Pietrucha et al. 1996). These treatments consisted of different combinations of centerline and edgeline markings, the use of raised pavement markers (RPMs), and roadside delineators mounted on different post types (e.g., standard and T-posts) with and without retro-reflectorization (Pietrucha et al. 1996). These combinations of delineation were presented in the driving simulator as “treatment blocks” which consisted of cinematic film footage presented to drivers for each of the different treatments being tested. Driver response to downstream roadway features or delineation were then measured for each treatment by recording brake pedal depressions that subjects were instructed to perform when they detected the treatment (Pietrucha et al. 1996). A total of 45 drivers participated in the simulator study. The results were collected and summarized by three age groups, including 18 to 45 years old, 65 to 74 years old, and 75 years old and older. The baseline roadway delineation treatment evaluated in the simulator was a 4- inch wide yellow centerline treatment.

The results of the simulator study described above were used to reduce the treatment combinations to a reasonable number that could be tested in a field study (Pietrucha et al. 1996). The results of the simulator tests provided an indication of the treatments that produced greater recognition distances when compared to the baseline situation (i.e., the yellow centerline stripe). Based on these results, 11 treatment combinations were eliminated from further consideration in the field study.

The field study portion of the Pennsylvania study was completed along a closed one-mile oval course in University Park, Pennsylvania (Pietrucha et al. 1996). Overall, 66 drivers were selected. Half of these drivers were 18 to 45 years old (16 females and 17 males) and half were at least 65 years old (14 females and 19 males). Two tests were completed to measure the effectiveness of the different treatment combinations of interest. First, two study subjects were asked, from a stationary vehicle, if they recognized a treatment 1,000 feet from the horizontal curve. Then, researchers measured the responses at 100-foot intervals until both subjects answered correctly. A visual occlusion test was also done with a visor that slowly lowered as a driver approached the horizontal curve. The drivers were asked to raise the shield when they felt uncomfortable as to the direction of the horizontal curve. The assumption with this test was that the better treatments would more clearly show the direction of the horizontal curve.

Based on the field study results, the researchers found that four of the treatments appeared to produce the most improved performance by older drivers while not having a detrimental effect on younger driver operations (Pietrucha et al. 1996). These fours treatments consisted of the following delineation: 1) a yellow centerline stripe, no edgeline marking, and chevrons, 2) a yellow centerline stripe, no edgeline markings, and T-post roadside delineator, 3) a yellow centerline stripe, raised pavement markers, no edgeline, and T-post delineators, and, 4) a yellow centerline, white edgeline markings, and T-post delineators. The fourth combination, overall, appeared to have the highest recognition values for the different age groups (Pietrucha et al. 1996). In addition, the static recognition and visual occlusion results for treatments with yellow centerline, with or without edgelines, and T-post delineators were statistically similar and provided the best overall performance by all of the drivers. Based on these findings, the researchers concluded that these treatments could be expected to improve performance for older drivers but not produce detrimental effects on younger drivers (Pietrucha et al. 1996).

Pavement-Marking Costs and Removal

In addition to the safety impacts of pavement markings, aspects related to their cost and removal were also of interest for this project. Some information, such as materials and costs, have been documented in literature. Other aspects, namely maintenance and removal, are not often discussed. Pavement marking maintenance is tied primarily to repainting markings, while decisions regarding when markings should be removed is a subject that is infrequently documented.

Cost of Pavement Markings

Hawkins and Smadi reported that the approximate costs of pavement marking materials per foot in Iowa averaged from \$0.09 to \$0.12 for waterborne paint (2010). Note that these costs were reported in 2010 dollars and reflected a full installation of markings (centerline and edgelines). *NCHRP Synthesis 306* also provided cost information for the different types of pavement-marking materials in use at the time (e.g., 2002) (Migletz and Graham 2002). Waterborne markings at that time were reported to cost an average of \$0.06 per linear foot at the state level and \$0.07 per linear foot at the county level (both averages being the result of costs between agency- and contractor-applied markings) (Migletz and Graham 2002). Note that these costs were in 2002 dollars.

Abboud and Bowman, as part of their discussion related to the scheduling of paint and thermoplastic striping replacement, also provided a summary of current costs (from 2002) (Abboud and Bowman 2002). They indicated that the combined cost of 4-inch white and yellow pavement markings per mile was $625, while 6-inch lines would cost $780 per mile (Abboud and Bowman 2002). The useful life of those pavement markings on a low-volume route (i.e., less than 2,500 vpd) was expected to be 22 months (Abboud and Bowman 2002). It was recommended that striping be replaced when minimum retroreflectivity thresholds were met (Abboud and Bowman 2002).

Sarasua et al. reported that the estimated cost for waterborne markings per linear foot in South Carolina was between $0.06 and $0.09 in 2012 (Sarasua et al. 2012). During installation, inspections should check color, marking thickness and width, glass bead application, and nighttime brightness. For future restriping, they recommended that this activity should be planned and coordinated to coincide with other maintenance activities such as shoulder blading (Sarasua et al. 2012).

Removal of Pavement Markings

NCHRP Report 759: Effective Removal of Pavement Markings focused on the removal of permanent and work-zone-related pavement markings (Pike and Miles 2013). Methods identified for removal included blasting (with high-pressure water, sand, hydroblasting, dry ice, shot blasting, crushed glass, or soda), grinding, burning, laser, chemical (acetone, methanol, xylene, etc.), and masking (Pike and Miles 2013). It was noted that grinding removal was the technique most commonly available to agencies and also had the lowest cost. Regardless of the approach used, however, it was recommended that a high percentage of the pavement-marking material be removed to avoid driver confusion (Pike and Miles 2013). In addition, it was suggested that, prior to the removal project, the selected approach should be used to remove markings in a non-critical area to ensure that the technique is effective and to determine whether it will cause damage to the roadway surface (Pike and Miles 2013). If the approach was not effective in removing markings or caused damage to the pavement, an alternative approach should be selected.

Summary of Findings

This literature review of pavement markings and their impacts examined research and documents that have discussed the safety and safety-related impacts of centerlines and/or edgelines along roadways, with a specific focus on low-volume roadways. Several projects in Louisiana have been completed that focused on pavement-marking impacts on vehicle position and crashes (Sun and Tekell 2005, Sun and Das 2012, Sun and Das 2014). These projects generally found that on tangent roadway sections, vehicles shifted toward the centerline during the day after edgelines were installed, but fewer vehicles crossed centerline. At night, they observed that the vehicles were more centrally located in their lanes after edgeline installation, but that the edgelines resulted in vehicles operating further away from the roadway edge. Along curved roadway segments, their conclusions about vehicle lateral placement after edgeline installation appeared to be mixed. However, they did observe more centerline encroachments (Sun and Tekell 2005). The relationships discussed between lateral placement and the factors they considered may also be suspect due to the correlations between variables (Sun and Tekell 2005). The Louisiana team also applied several safety analysis approaches that were described in two documents (Sun and

Das 2012, Sun and Das 2014, Sun et al. 2014). The most robust safety analysis completed in Louisiana, and the most useful, found a reduction of 15 percent when edgelines were added on narrow roads (i.e., 22 feet or less) and they calculated benefit-cost ratios ranging from 75.56 to 117.58 (based on contractor versus department installation) (Sun and Das 2012, Sun and Das 2014, Sun et al. 2014).

This chapter also included summaries of crash trends from Kentucky, Pennsylvania, Texas, and Virginia (Agent and Green 2008, Tsyganov et al. 2006, Tsyganov et al. 2005, Dougald et al. 2013, Kweon et al. 2015, Pietrucha et al. 1996). In Kentucky, the authors recommended that centerline and edgeline markings be used on roadways with a lane width of 9 feet, centerlines only for roads with a lane width of 8 feet, and edgelines only for roads narrower than 8 feet (Agent and Green 2008). In addition, the Pennsylvania study indicated that yellow centerlines without an edgeline but in combination with features such as delineators or chevrons improved driver recognition of roadway geometry (Pietrucha et al. 1996). In Texas, researchers found edgelines reduced crashes by up to 26 percent, but the greatest reductions were along roadways with lane widths of 9 to 10 feet (Tsyganov et al. 2006). A follow-up with laboratory and field tests found that edgelines should be used on pavements with a width of at least 21 feet 9 inches, and applications on narrower pavements should be left to engineering judgement (Tsyganov et al. 2005).

The literature related to pavement-marking costs and removal indicated that approaches to application and maintenance are based on condition inspections or a time-based interval (yearly, biyearly, remaining service life, etc.) (Hawkins and Smadi 2010, Lund and Cox 2014, Sarasua et al. 2012). Limited cost information available in the literature showed a general range of $0.06 to $0.12 per foot per marking for waterborne paint. Much of this information, however, was older (i.e., pre-2010). Finally, commonly accepted removal methods in the literature include blasting, grinding, burning, chemicals, and masking (Migletz and Graham 2002). These methods can be used, but cost can be a limiting factor. In addition, “ghost” markings may remain.

In summary, the body of literature about the safety effectiveness of pavement markings (particularly on low-volume roadways) is limited. Most studies that focused on edgelines appeared to indicate that they produced a safety benefit, but the studies varied in terms of the statistical rigor. Overall, they produced a wide range of crash reduction values (e.g., 3 to 32.9 percent crash reduction).

CHAPTER 3. LEGAL CONSIDERATIONS

One of the tasks included in this research project was the pursuit of some legal input, from a practicing attorney, about the liability issues connected to traffic control devices from the perspective of a local municipality. This task was completed by approaching the Iowa State Association of Counties (ISAC), which obtained an opinion from the Iowa Communities Assurance Pool (ICAP). The opinion letter is provided in Appendix A and was prepared by a staff member from a firm in Council Bluffs (Madsen 2015). The letter provides a discussion of the protections offered to State and municipalities in Iowa by specifying the Iowa Code that applies, §668.10(1)(a) (State of Iowa Code 2015b), and stating the following (see Appendix A):

> "In its simplest interpretation, a municipality cannot be held liable for failing to place, erect or install traffic control devices, on any type of road, including low-volume, paved roadways. However, once the traffic control device has been installed, a municipality can be assigned fault if the municipality does not properly and adequately maintain the device."

The statement is also supported by a short discussion related to this immunity and traffic control devices. Two specific points made in the letter include the following:

> "The immunity granted to municipalities applies to all such placements or installation and thus a claim that the municipality should have done more to warn motorists or should have installed more traffic control devices does not overcome the immunity. *McClain v. State*, 563 N.W.2d 600 (Iowa 1997)."

> "It even applies when the state or local government creates a road hazard through its own maintenance or construction and fails to erect warning signs. *Foster v. City of Council Bluffs*, 456 N.W.2d 1 (Iowa 1990). Section 668.10(1)(a) immunity also applies to state contractors and subcontractors who comply with the State's plans and specifications and who are not negligent in performing the work. *McLain v. State,* 563 N.W.2d 600 (Iowa 1997)."

The letter provided by ISAC from ICAP, however, also included a discussion of exceptions to this statutory immunity. There are three of these type of exceptions and they include: "…(1) claims for failure to maintain a device; (2) claims for the installation of a misleading sign; and (3) claims that exigencies are such that ordinary care would require the state or municipality to warn of dangerous conditions by other than inanimate devices. *Hunt v. State*, 538 N.W.2d 659 (Iowa Ct. App. 1995); *Estate of Oswald v. Dubuque County*, 511 N.W.2d 637 (Iowa Ct. App. 1993)." Each of these exceptions is supported by a discussion of case law and other information. The reader is referred to Appendix A and encouraged to read the letter provided in its entirety. There is additional information and detail that is not included in the summary above. The general conclusion of the research team is that this information supports what is commonly known in Iowa about municipal immunity and the need to maintain traffic control devices once they are installed.

CHAPTER 4. PAVEMENT-MARKING USE SURVEY

On March 27, 2014, an eight-question survey was distributed to county engineers in Iowa to investigate and quantify current pavement-marking practices along low-volume rural roadways (i.e., an ADT of less than 400 vpd). The survey included questions about pavement-marking practices along paved (i.e., hot-mixed asphalt (HMA) and Portland cement concrete (PCC) surfaces) and seal-coated roadways. In addition, it asked about the factors considered when an agency determines whether to paint centerlines and/or edgelines. This chapter summarizes the responses to the pavement-marking survey completed as part of this project.

Survey Description

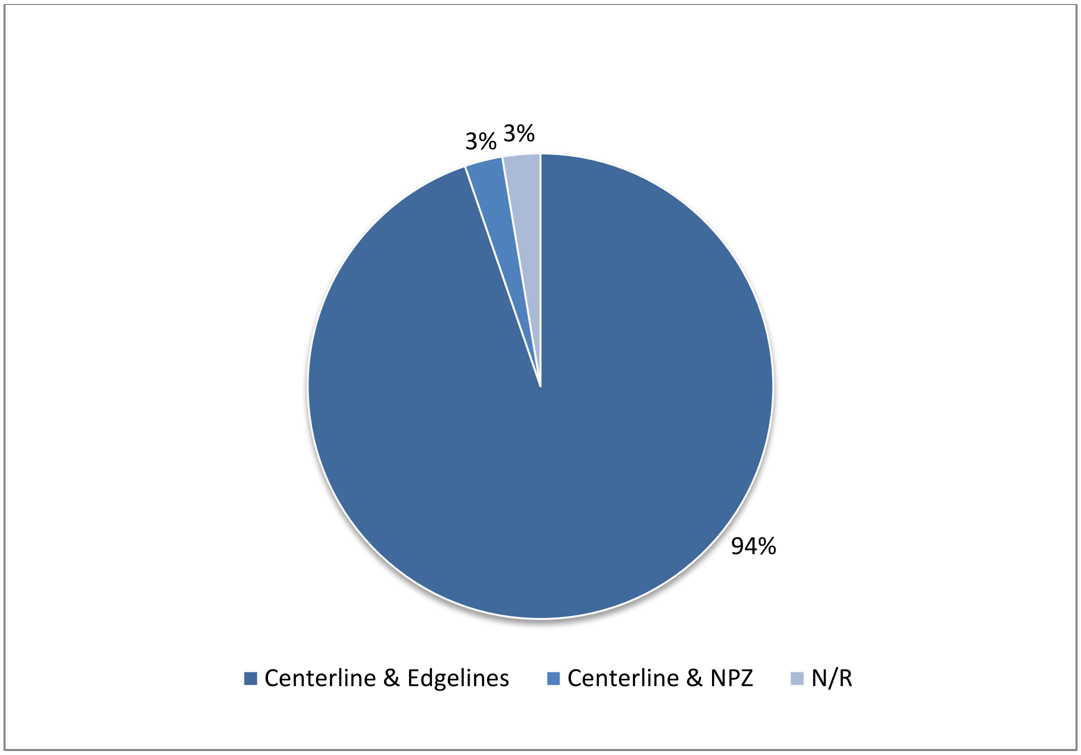
The pavement-marking survey completed as part of this project was distributed to the 92 engineers that oversee the secondary roadway system in the 99 Iowa counties. A total of 37 county engineers (approximately 40 percent) responded. The survey participants were asked eight questions (including their county name). These questions are presented in Appendix B.

The first set of questions in the survey focused on the type and extent (i.e., percent mileage) of pavement markings used by the county engineers along low-volume HMA, PCC, and seal-coated roadways. Seal coats in Iowa have been used to extend the life of existing pavements (e.g., HMA) and also along roadways with little to no supporting base structure. The respondents, therefore, interpreted the questions related to seal coats in the context of their county. A county could include one, both, or neither of the seal coat approaches previously described. The pavement type and extent questions were followed by those that focused on pavement-marking installation criteria (e.g., roadway classification, pavement width, etc.). The survey participants were generally asked to answer these questions only if they didn’t install pavement markings along all of their hard surfaced low-volume roadways. Finally, a series of questions was asked that focused on pavement-marking replacement intervals and cost. The answers to all questions in the survey (except county name) are summarized below.

Survey Results

Type of Pavement Markings Used

The first pavement-marking-related question asked of the survey respondents was about the type of pavement markings used on paved (i.e., HMA/PCC) and seal-coated roadway surfaces. For each roadway surface, the respondents could select from centerline/no passing zone (NPZ) only or centerline and edgeline options. As shown in Figure 1, practically all of the respondents (95 percent, n = 35) stated that they applied centerline and edgelines on their paved roadways.

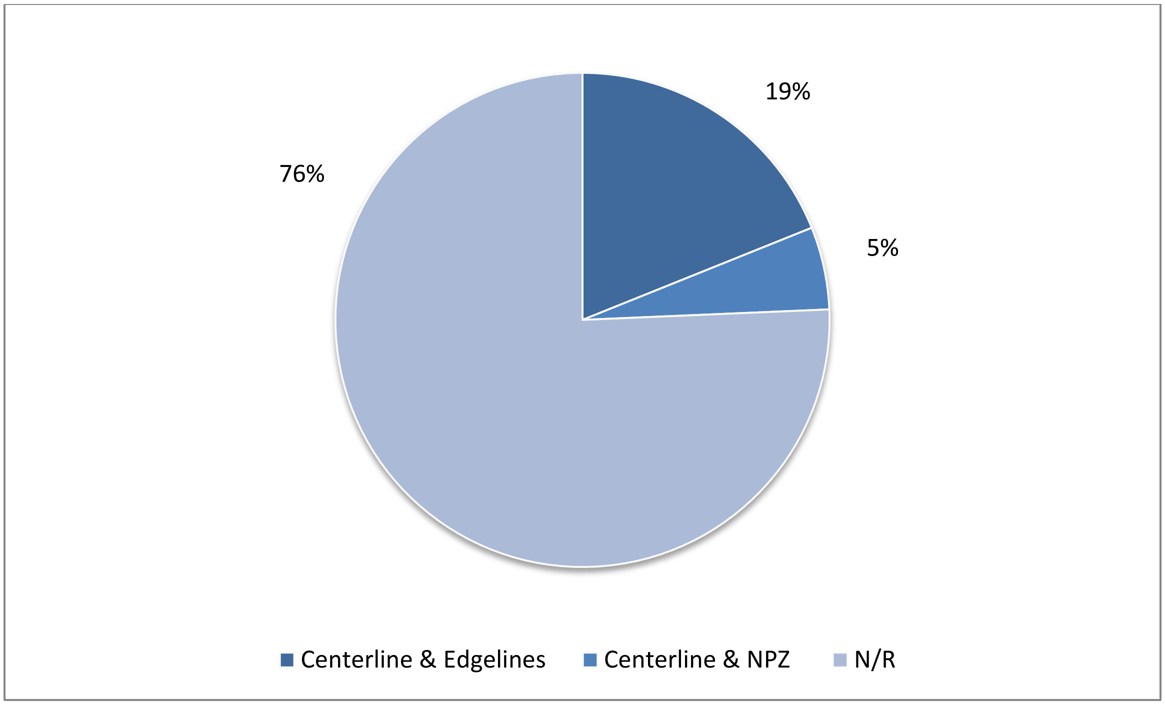


NPZ=no passing zone, N/R=no response, and percentages vary based on rounding

Figure 1. Pavement-marking applications on low-volume paved roadways

One respondent (3 percent) indicated they used centerline/NPZ only, and one (3 percent) did not answer the question (i.e., was non-responsive (N/R)). It appears that the non-responsive survey participant did not believe either answer was applicable to their application of pavement markings.

The results from the question about pavement marking type along seal-coated roadways are shown in Figure 2.



NPZ=no passing zone, N/R=no response, and percentages vary based on rounding

Figure 2. Pavement-marking applications on seal-coated roadways

In general, the majority of the respondents (76 percent, n = 28) did not answer the question (i.e., were N/R). However, 19 percent (n = 7) indicated that they paint both centerline and edgelines on their seal-coated roadways, and two (5 percent) of the respondents just paint centerline/NPZs. Those that did not respond to the second question may not have low-volume seal-coated roadways or they may have felt that the part of this question that focused on paved surfaces was a more appropriate response because they only use seal coats along paved (e.g., HMA) roadways. It should also be noted that, because the question only allowed one pavement-marking approach to be selected for each roadway surface, the respondents likely choose the one they use most often and they could be using both approaches. The questions that more specifically explore the extent to which each pavement-marking approach is used along the two roadway surfaces are summarized in the next section of this report.

Extent of Pavement Markings Used – Paved Roadways

Additional survey questions explored the extent of the pavement markings (see Figure 1 and Figure 2) used by the respondents. The survey participants were asked to approximate the percentage of their paved (e.g., HMA/PCC) and seal-coated roadways that had just centerline/NPZ markings or a combination of centerline/NPZs and edgeline markings. In each case, the respondents were presented with the choices of 100, 75, 50, 25, and 0 percent or the ability to choose “other” and explain a different answer. Three of the responses to this question were removed from further consideration because there appeared to be some confusion in the answers. Therefore, 34 responses are summarized below.

The answers related to the extent of pavement markings along paved (e.g., HMA/PCC) roadways are summarized in Table 1.

Table 1. Percentage of pavement-marking types on paved roadways

Percentage of Roadway	Centerline/NPZ Only (Percent of Responses)	Centerline/NPZ and Edgeline (Percent of Responses)
100	0	82 (n = 28)
75	6 (n = 2)	9 (n = 3)
50	0	0
25	9 (n = 3)	3 (n = 1)
0	15 (n = 5)	3 (n = 1)
N/R	70 (n = 24)	3 (n = 1)

N/R = Non-Responsive; percentages may not sum to 100 percent because of rounding

A total of 5 (or 15 percent) of the survey respondents indicated that they use centerline/NPZ pavement markings only along their paved roadways. Six percent (n = 2) indicated they paint approximately 75 percent of their paved roadways in this manner, and 9 percent (n = 3) did the same for about 25 percent of these roadways. Finally, another 15 percent (n = 5) of the respondents indicated that they don't apply centerline/NPZs along any of their paved roadways and another 70 percent (n = 24) did not respond to this part of the question. A non-response to this question likely means that they did not feel that it applied to their situation.

Overall, a general interpretation of the results described above is that a response of 0 percent to this question or an N/R (i.e., no response) likely have the same meaning in most cases. Therefore, approximately 85 percent of the respondents to this question do not use the centerline/NPZ-only marking approach on their low-volume paved roadways. A further investigation of the answers also revealed that one respondent answered 0 percent to both pavement-marking approaches along their paved roadways. This response may mean the respondent did not believe the question applied to their situation. In addition, another respondent answered that the centerline/NPZ-only pavement-marking approach was used on 75 percent of their low-volume paved roadways, but the same respondent answered N/R related to the use of centerline/NPZ and edgeline use. It was concluded that this combination of answers might mean that pavement markings were not used along 25 percent of this respondent's paved roadways. Finally, it also appears that there may be at least five counties that apply only centerline/NPZs (without edgelines) along their paved roadways (in addition to their use of the centerline/NPZ and edgeline approach). It should be noted that, in the initial question of the survey (described previously), the respondents were only allowed to select one pavement-marking approach for each roadway surface. They likely selected the approach they used most often. This question, on the other hand, allowed them to specifically indicate how much they used each pavement-marking approach on paved and seal-coated surfaces.

Respondents were also asked to approximate the percentage of paved roadways along which they used a combination of centerline/NPZ and edgelines. All but two of the survey respondents (n = 34) indicated they used this approach on some percentage of their low-volume paved roadways.

As noted previously, one respondent answered 0 percent to the use of both types of pavement-marking approaches (i.e., it was not applicable to their situation). In addition, one survey participant did not respond to this question. However, a large majority (82 percent, n = 28) of the respondents indicated that 100 percent of the low-volume paved roadways in their county used the centerline/NPZ and edgeline pavement marking approach. In addition, another 9 percent (n = 3) of the respondents indicated that approximately 75 percent of their paved roadways were marked using this approach, and 3 percent (n = 1) said that this applied to approximately 25 percent of their paved roadways. Overall, more than 90 percent of respondents indicated they use centerline/NPZ and edgelines combined along 75 percent or more of their paved roadways. In one case, it was also noted that there was a centerline/NPZ-only pavement marking approach with a low number of miles that was significantly below 25 percent but not 0 percent. A summary of these percentages is shown in Table 1.

Extent of Pavement Marking Used – Seal-Coated Roadways

Survey respondents (county engineers) were also posed the same question as described above for seal-coated roadways under their jurisdiction. The results to this question are summarized in Table 2.

Table 2. Percentage of pavement-marking types on seal-coated roadways

Percentage of Roadway	Centerline/NPZ Only (Percent of Responses)	Centerline/NPZ and Edgeline (Percent of Responses)
100	0	8 (n = 3)
75	0	5 (n = 2)
50	5 (n =2)	0
25	8 (n = 3)	0
0	41 (n = 15)	51 (n = 19)
N/R	46 (n = 17)	35 (n = 13)

N/R = Non-Responsive; percentages may not sum to 100 percent because of rounding

Overall, 87 percent (n = 32) of the respondents indicated that they do not use centerline/NPZ pavement markings on any of their seal-coated roadways or they did not respond (N/R) to the question. As noted previously, it was generally assumed that a response of 0 percent and N/R generally had the same meaning with regard to pavement-marking usage. In other words, either they did not mark their seal coats or they did not have any seal-coated roadways. However, approximately 8 percent (n = 3) of those responding indicated that they use centerline/NPZ markings along approximately 25 percent of their seal-coated roadways and another 5 percent (n = 2) followed the same pavement approach for approximately 50 percent of these roadways. Further evaluation of these five individual results appeared to show that at least three of the five did not use pavement marking on the remainder of their seal-coated roadways.

Survey participants were also asked about the approximate percentage of seal-coated roadways along which they used a combination of centerline/NPZs and edgelines. The answers to this question are also summarized in Table 2. In this case, the overwhelming majority (86 percent, n

= 32) indicated that 0 percent of their seal-coated roadways had this combination of pavement markings or they were N/R. As noted previously, in most cases, it is assumed that these two answers have a similar usage meaning (i.e., that the county either uses this approach on 0 percent of their existing seal coat roadways or there are no seal-coated roadways in the county). However, approximately 8 percent (n = 3) of the respondents indicated that 100 percent of their seal-coated roadways had centerline/NPZ and edgelines, and another 5 percent (n = 2) said they followed this approach with 75 percent of these type of roadways. In one case, a respondent indicated that none of their seal coats had any pavement markings, but the respondent also noted there were a few miles of seal-coated roadways with some edgelines along a five-foot trail next to the roadway.

Application Criteria – Paved Roadways

A third set of questions in the survey focused on application criteria. Respondents were asked what they used to determine the application of pavement markings along their paved (i.e., HMA/PCC) roadways if they didn't apply markings along 100 percent of their mileage. The survey allowed the respondent to select one or more of the following as potential criteria: roadway classification, pavement width, traffic volume, or "other." The option of "other" provided a space to describe the factors that might be considered to apply pavement markings along their paved roadways. A total of 40 responses were received, and six (15 percent) of the responses indicated that traffic volume was used as a factor to determine if a paved roadway should receive pavement markings. In addition, one response (3 percent) indicated that they consider pavement width as an application factor, and another considered vehicle speed. More specifically, it was noted that no pavement markings were applied on paved or seal-coated roadways with a speed limit less than 35 mph. Overall for this question, however, the majority of the responses (80 percent, n = 32) were left blank, indicated the question was "not applicable (N/A)," or noted in the "other" field that eventually all of their roadways would be seal-coated and include centerline/NPZ markings.

Application Criteria – Seal-Coated Roadways

Respondents were also asked what they used to determine the application of pavement markings along their seal-coated roadways if they didn't apply markings along 100 percent of their mileage. Once again the survey participants were given the choice of selecting one or more of the following: roadway classification, pavement width, traffic volume, and "other." A total of 39 responses were received, and 10 percent (n = 4) indicated that they used traffic volume as an application criteria. In addition, three percent (n = 1) of the responses indicated the county used pavement width as a factor in the application of pavement markings along seal-coated roadways, and five percent (n = 2) stated that roadway classification was used. There were also two responses in the "other" category that were relatively unique. One county also indicated they used horizontal alignment to determine pavement marking on seal-coated roadways and another does not use pavement marking on seal-coated roadways with no pavement base, but does use centerline/NPZs on those with a pavement base. Overall, once again, the majority (77 percent, n = 30) of the responses were left blank, indicated "not applicable (N/A)," that they didn't have seal-coated roadways, or that they did not use pavement markings along these type of roadways. In other words, this question was not relevant to, or did not apply within, their county.

Replacement Intervals – Paved Roadways

The next series of questions in the survey focused on pavement-marking replacement intervals. The survey participants were asked to separately estimate how often they replace their centerline/NPZ markings and edgelines along both paved and seal-coated roadways. The respondents could choose from the following replacement intervals: 2 years, 3 years, 4 years, and "other." They were also asked to explain any "other" responses (e.g., annually). The answers related to pavement-marking replacement intervals varied widely, but 43 percent (n = 16) of the survey participants estimated that they re-paint centerline/NPZs along their paved roadways every 2 years. In addition, approximately 14 percent (n = 5) of the respondents noted they take this action every 3 years, and approximately 22 percent (n = 8) noted in the "other" option that they replace these pavement markings every year. "Other" replacement approaches were also used. Some of these "other" approaches included painting one half of the centerline/NPZs within the county each year and another was that the pavement markings were replaced when they appeared to be fading (i.e., a visual inspection). It should be noted, however, that these "other" approaches typically were not explained separately for centerline/NPZ and edgeline pavement markings and it was assumed they applied to both. In addition, approximately 5 percent (n = 2) of the survey participants did not answer the question. Some participants also marked "other," but did not give an explanation on how the replacement interval was determined.

The results to this question were similar to the above for edgeline replacement intervals along paved roadways. The survey responses for edgeline replacement intervals of 2, 3, and 4 years represented 46 percent (n = 17), 19 percent (n = 7), and 8 percent (n = 3) of the total number of answers provided, respectively. As noted above, some of the survey participants also indicated that they used other factors to determine when edgeline painting was needed. It was generally assumed that these "other" approaches applied to both centerline/NPZ and edgeline replacement (and they are described in the paragraph above). The "other" factors generally included, however, painting half of the edgelines in the county each year and checking visually to determine if replacement was needed. None of the respondents indicated they replaced edgelines on HMA/PCC roadways every year, and 11 percent (n = 4) did not answer the question or explain their "other" response.

Replacement Intervals – Seal-Coated Roadways

Respondents were also asked replacement interval questions for centerline/NPZs and edgeline pavement marking along their seal-coated roadways. The responses to previous questions, however, indicated that there are a limited number of counties in Iowa that have and/or place pavement markings along their seal-coated roadways. Not surprisingly, therefore, approximately 84 percent (n = 31) of the survey participants did not respond to this question. Eleven percent (n = 4) of the survey participants did indicate they paint centerline/NPZs along their seal-coated roadways every 2 years, 3 percent (n = 1) paint these pavement markings every year, and 3 percent (n = 1) indicated they take this action every 3 years. Similar responses were also provided when the survey respondents were asked how often they replaced their edgelines along seal-coated roadways. Only 5 percent (n = 2) of the respondents indicated they replace their edgelines on seal-coated roadways every 2 years, and an equal number of respondents (n = 2) paint edgelines along seal-coated roadways every 3 years. In addition, one respondent did indicate that another interval is used for their edgeline pavement-marking replacement, but no further explanation was given.

Pavement-Marking Cost Estimates

The last survey question focused on the cost of pavement markings. The survey participants were asked to provide a cost estimate per station (100 feet) for their pavement markings. Unfortunately, the question did not ask for costs by the two types of pavement markings (centerline/NPZ and edgeline), so some interpretation of the answers was required. This interpretation was based on a few answers that did provide this level of specificity (without being asked) and the answers provided to previous questions (i.e., which pavement markings do you use). It was concluded that about 10 of the answers should be ignored because they did not appear to be provided by station. In addition, it was also assumed that none of answers applied to only edgelines because none of the counties used this pavement-marking approach on their roadways. In general, it appeared that the answers showed an estimated cost for centerline/NPZ markings of $3.25 per station to $5.00 or $6.00 per station. The estimated cost for a combination of centerline/NPZs and two edgelines, on the other hand, appeared to range from $11.00 to a little more than $14.00 per station. In addition, there were also three answers in the $8.50 to $9.25 per station range, and it was assumed that these might be cost estimates for the centerline/NPZ and one edgeline pavement marking (rather than two edgelines).

Summary of Findings

The objective of the survey was to better define the pavement-marking practices in Iowa along low-volume rural roadways. Overall, the survey showed that approximately 95 percent (n = 35) of the respondents apply a centerline/NPZs and edgelines along at least some of their paved low-volume roadways. In fact, 82 percent (n = 28) of the counties responding to the survey applied both centerline/NPZs and edgelines along all of their paved low-volume roads, regardless of traffic volumes, lane width, road classification, or “other” factors. Another 9 percent (n = 3) of respondents stated that approximately 75 percent of their paved roadways were marked with a centerline/NPZ and edgeline combination. None of the counties responding to the survey indicated that 100 percent of their low-volume paved roadways had just a centerline/NPZ marking and no edgelines. In addition, only 15 percent (n = 5) used this practice on 25 to 75 percent of their paved county roadways. Overall, the survey also showed that centerline/NPZ and edgeline pavement markings along low-volume paved roads were typically replaced every 2 years (43 percent or 16 of the responses), and 22 percent (n = 8) of respondents noted that they accomplished this replacement every year. A total of 15 percent (n = 5) repaint these lines every 3 years, and a few of the respondents indicated that they use a visual check to determine if replacement is needed.

Along seal-coated roads, the responses varied more widely than those for paved roadways. In general, the majority (76 percent, n = 28) of respondents either did not answer these questions or indicated that the seal-coated roadway questions did not apply to them. It is assumed that this lack of response was because they either don't use pavement markings on their low-volume seal-coated roadways or they do not have seal-coated roadways. An additional point of confusion with the questions is that Iowa has seal coat surfaces along roadways with a pavement base (e.g., HMA) and along roadways with less of a support structure. The respondents were required to interpret this question for their situation. Overall, however, 19 percent (n = 7) of the respondents who did use pavement markings on their seal-coated roadways stated that they use a combination of centerline/NPZ and edgeline markings, while 5 percent (n = 2) only use centerline/NPZs. Eight percent (n = 3) of respondents indicated that they mark approximately 25 percent of their seal-coated roadways using just the centerline/NPZ approach and five percent (n = 2) stated that they do the same along 50 percent of roadways. The use of a centerline/NPZ and edgeline pavement-marking approach was also similarly split, with 8 percent (n = 3) of the respondents indicating that they use both pavement markings on 100 percent of their low-volume seal-coated roadways and 5 percent (n = 2) use them on 75 percent of these roadways. Overall, more than 84 percent (n = 31) of the survey respondents didn't answer the pavement marking-replacement interval question for seal-coated roadways, but about 11 percent (n = 4) replace their centerline/NPZs along these roadways every 2 years. A similar amount, about 5 percent (n = 2) of the respondents also indicated they replace their edgelines on seal-coated roadways every 2 years. Other respondents indicated replacement of pavement markings along seal-coated roadways either annually or every 3 years. At least one respondent also indicated they use a visual check to determine the need for replacement.

The last question in the survey focused on the cost of pavement markings. This question in the survey, unfortunately, did not ask the respondents to provide the costs of centerline/NPZ and edgelines separately. Therefore, some of the answers appeared to apply to only centerline/NPZs and others were likely for a combination of centerline/NPZs and edgelines. An interpretation of the answers was needed, and overall it appeared that some of the answers showed an estimated cost for centerline/NPZ markings in a range from $3.25 per station to $5.00 or $6.00 per station. Others answers appeared to estimate the cost for a combination of centerline/NPZs and two edgelines, and these estimated costs ranged from $11.00 to a little more than $14.00 per station. Finally, there were also three answers in the $8.50 to $9.25 per station range and it was assumed that these might be cost estimates for the centerline/NPZ and one edgeline pavement marking.

CHAPTER 5. BASIC SAFETY EVALUATION

An exploratory analysis of pavement-marking benefits and costs was also completed as part of this project. More specifically, given the current state of knowledge, the percent total crash reduction required to produce a benefit-cost ratio of 1.0 was calculated. This calculation was completed for paved and seal-coated roadways with either centerline/NPZ only or centerline/NPZ and edgeline marking configurations. The intent of this estimate was to better understand the point where the potential total crash reduction benefits of pavement-marking use might exceed the cost of pavement-marking installation. The approach for this calculation considered a one-mile segment of roadway and employed average costs for centerline/NPZ and centerline/NPZ and edgeline combinations. Statewide average crash densities (in crashes per mile) by severity for paved and seal-coated secondary roadways were also used. The following text provides an overview of the site, input data, calculation, and results that were found in this evaluation.

Site Description

The site used for this evaluation was a hypothetical one-mile (i.e., 52.8 stations) segment of paved and seal-coated secondary roadway in Iowa. This one-mile segment is assumed to have no pavement markings. By using a hypothetical segment, it was possible to estimate the potential percent reduction in total crashes that would be required to achieve a benefit-cost ratio of 1.0.

Pavement-Marking Costs

One input to this process was pavement-marking cost. Pavement-marking cost information by station was obtained from Iowa counties through the survey discussed previously and also from annual bid information kept by the Iowa DOT (BidExpress 2015). The Iowa DOT bid values represented the cost of waterborne paint applied per station and were reported for each individual line. The costs used in this process are summarized below.

First, an interpretation of the pavement-marking cost results from the county survey for centerline/NPZ markings appeared to show a range from $3.25 per station to $6.00 per station. The midpoint of this range of data is $4.63 per station. The Iowa DOT minimum bid value was $4.25 per station. This cost value is in line with those reported by Iowa counties. Based on this, the midpoint reported by the counties was used in this calculation. The cost per mile calculated for this pavement-marking approach was $244.46.

Second, the county pavement-marking survey responses appeared to show an estimated cost for a combination of centerline/NPZs and two edgelines from $11.00 to approximately $14.00 per station. The midpoint cost for these three lines is approximately $12.50 per station. The Iowa DOT minimum bid value for this pavement-marking approach was $12.75 per station. This number is in line with what was reported by the counties surveyed. Based on this, the midpoint cost reported by counties was used in this calculation. The cost per mile calculated for this pavement-marking approach was $660.00.

Secondary Road Crash Densities

A second input to this process was average crash densities. These averages, by severity, for secondary roadways were obtained from the Iowa DOT Office of Traffic and Safety for a 10-year period (2002 through 2011) (Iowa DOT 2013). The report used represented the latest cumulative data that had been compiled. The secondary roadway average crash densities per mile by severity for paved and seal-coated surfaces are presented in Table 3.

Table 3. Secondary roadway average crash densities by surface type and severity

Paved Surface	
Severity	**Crashes per mile**
Fatal	0.01
Major	0.02
Minor	0.05
Possible	0.06
PDO	0.26
Seal Coat Surface	
Severity	**Crashes per mile**
Fatal	0.00
Major	0.02
Minor	0.05
Possible	0.05
PDO	0.20

PDO = Property Damage Only

The "cost" of the average crash densities per mile in Table 3 were also calculated as part of this process. These densities were multiplied by the costs used in Iowa for each severity level. The costs used in Iowa for each severity level are as follows:

- Fatal = $4,500,000
- Major Injury = $325,000
- Minor Injury = $65,000
- Possible Injury = $35,000
- PDO = $7,400

These "cost" values are based on several factors and reviewed by Iowa DOT on a relatively regular basis. More information on these costs can be found in the Office of Traffic and Safety Traffic Safety Improvement Program (TSIP) Benefit-Cost Worksheet (Iowa DOT 2015). An assumption that was used in this benefit-cost analysis for pavement marking is that one fatality or one injury was produced by each fatal crash or injury crash, respectively. It should also be noted that these average crash densities are for all secondary roadways and not only for low-volume roadways. In addition, these averages include all different types and approaches to pavement markings. In reality, the density averages may be different for different marking approaches.

Percent Crash Reduction Calculation

The cost and crash information previously described was used to calculate the potential percent total crash reduction required to produce a benefit-cost ratio of 1.0 along a one-mile segment of secondary roadway. A benefit-cost ratio of 1.0 represents the point at which the cost of pavement markings is expected to be exceeded by the crash reduction cost savings. The following equation was used to calculate this reduction: Percent Crash Reduction = (Pavement Marking Cost per Mile ÷ Annual Crash Cost per Mile) × 100. A percent crash reduction was calculated for total crash cost (the cost of all crash densities by severity summed).

The first evaluation completed focused on the potential percent crash reduction required to produce a benefit-cost ratio of 1.0 for centerline/NPZ markings. Overall, it was found that a percent reduction for total crashes of only 0.42 percent (total crashes) along a paved roadway was needed for a benefit-cost of 1.0. Similarly, along a seal-coated roadway, the percent reduction needed for a benefit-cost of 1.0 would be approximately 1.9 percent.

A similar evaluation was completed for the use of centerline/NPZ and edgeline markings along paved and seal-coated secondary roadways. Overall, it was found that a total crash percent reduction of only 1.1 percent was needed along a paved roadway for a benefit-cost ratio of 1.0. Similarly, along a seal-coated roadway, the percent reduction needed for a benefit-cost of 1.0 would be approximately 5.1 percent. The percent reduction results clearly illustrate the impact of the different average severities per mile and the differences in their “cost” per mile.

Summary of Findings

The approach taken in this chapter was based on a conclusion by the research team that the published literature on crash reductions due to installation of basic pavement markings is relatively limited in number and robustness. This is particularly true for rural, two-lane, low-volume roadways. In fact, the majority of the literature summary in this report focused on the application of edgelines and their impact. Information on the application impacts of centerline/NPZ from the *HSM* and CMF Clearinghouse reference one study that indicated a total crash reduction from the addition of centerline/NPZ pavement markings ranged from -1 percent (for PDO crashes) to 1 percent (for serious and minor injury crashes) (AASHTO 2010). The study referenced was rated with three stars out of five and the *HSM* recommends that these be used with caution. The total percent crash reductions calculated in this basic evaluation were about 0.42 and 1.9 percent for paved and seal-coated roadways, respectively. These percentages are in the range of those found by the study reference in the *HSM* and CMF Clearinghouse. Our evaluation generally indicates that there is very little crash reduction needed to justify the addition of these pavement markings. This is not surprising given their inherent value and the expectation and use of their application by the driving public.

The percent crash reductions for the installation of centerline/NPZ and edgeline markings from the *HSM* and CMF Clearinghouse, as well as the work summarized earlier in this document, range, depending on severity of crash, from 10 percent to 24 percent for two-lane rural roadways. The *HSM* includes a percent reduction for serious and minor injury crashes of 24 percent (AASHTO 2010). The total percent crash reductions in this basic evaluation for the installation of centerline/NPZs and edgelines were 1.1 and 5.1 percent for paved and seal-coated roadways, respectively. These percentages are smaller than the reductions found in the literature. Once again, our evaluation shows the low level of total crash reductions that would be needed, on average, in order to make pavement markings beneficial. Ultimately, pavement markings serve several needs for the driving public.

Overall, the calculations done here were general in nature and considered only a hypothetical one-mile segment. They were intended to illustrate the point at which the application of pavement markings may begin to produce crash reduction benefits. The percentages are very small. However, further research is necessary to establish the true crash reductions that can be attributed to pavement-marking configurations on low-volume roads. One possible approach to this would be a comparison of similar roadway segments with and without pavement markings. This type of evaluation, however, was beyond the scope of this project.

CHAPTER 6. CONCLUSIONS AND RECOMMENDATIONS

This project focused on the pavement-marking practice in Iowa along low-volume roadways. The tasks included were a literature review and summary of pavement-marking characteristics (e.g., application guidance and requirements; safety and/or operational impact research; and, cost and removal techniques), description of legal considerations connected to traffic control devices, a survey of pavement-marking practices in Iowa, and a basic benefit-cost safety evaluation. The conclusions and recommendations based on the results of these tasks are described below.

Conclusions

- The standard or required pavement-marking information provided in the *MUTCD* generally applies to facilities other than low-volume (400 vpd or less) roadways. The decision to install pavement markings along low-volume roadways is currently based on engineering studies and/or judgement (FHWA 2009).

- Several other documents were also summarized that provided some pavement-marking application guidance. In one case, the pavement service life remaining was used to determine the time for pavement-marking replacement and recommend the type of pavement marking to apply (Hawkins and Smadi 2010). In another case, the function of a roadway was used in one county to determine what pavement markings to place and how often they should be replaced (Lund and Cox 2015). The county applied centerlines to all county roadways and edgelines to its arterials and collectors. In addition, edgelines were also installed along roadways in the county road safety plan, and their replacement plan for centerline pavement markings was related to surface condition ratings. Their policy for edgelines was to replace them every 3 years. Lastly, a study in South Carolina recommended waterborne pavement markings for roadways with less than 1,000 vpd (Sarasua et al. 2012).

- A summary of several research documents related to the safety and/or operational impacts of pavement markings was completed as part of this project. The overall results were limited for low-volume roadways, but projects from several states are described in this report. These projects had a wide range of robustness and results. An edgeline analysis completed in Louisiana focused on rural narrow roadways and appeared to be one of the most relevant to this project. Its operational analysis of vehicle position due to the addition of edgelines along narrow roadways showed some mixed results, but its safety analysis indicated a 15 percent reduction in total crashes (Sun and Das 2014). The pavement-marking study referenced in the *HSM*, on the other hand, indicates that the addition of a centerlines may or may not have an impact on injury or PDO crashes (AASHTO 2010). In fact, the *HSM* recommends that the CMF it includes for centerlines be used with caution. The study the *HSM* includes for the application of a combination of centerline and edgelines, however, shows a 24 percent reduction in injury crashes (AASHTO 2010). More research is clearly needed on the actual safety impacts of pavement markings, regardless of roadway volume.

- The legal consideration completed and summarized as part of this project did not appear to add to the general state-of-the-knowledge. The input on this subject included in this report and its appendix generally summarized the factors connected to local immunity in the state of Iowa and also indicated that traffic control devices, once installed, are required to be maintained.

- The pavement-marking survey that was completed as part of this project produced some interesting results. A total of 37 county engineers responded to the survey. Overall, based on the responses provided, it would appear that the majority of the paved secondary roadways in Iowa have both centerline and edgeline pavement markings. Seal-coated secondary roadways, on the other hand, if they exist in a county, might have a centerline/NPZ, a combination of centerline/NPZ and edgeline pavement markings, or no pavement markings at all. The most common replacement interval for pavement markings is one or two years and the typical cost per station (100 feet) appears to range from approximately three dollars per station to about six dollars per station (for an individual centerline or edgeline marking).

- The basic benefit-cost safety evaluation completed as part of this project revealed that the total crash reductions due to pavement markings do not need to be very large in order to produce benefits that are larger than their cost. The overall crash reductions needed ranged from 0.42 percent to 5.1 percent, depending on the combination of markings used. These reductions are within the range of safety impact study results summarized as part of the literature review completed for this project. It should also be noted that the benefits of pavement markings are not completely described by this evaluation (i.e., there are other driver behavior, etc. benefits to the installation of pavement markings). The evaluation, however, shows the low level of total crash reductions that would be needed, on average, in order to make pavement markings beneficial.

Recommendations

The following recommendations were developed from the completion of the tasks included in this project.

- There is a gap in the state-of-the-knowledge related to the safety impacts from the installation of pavement markings. The need for this type of information appears to have increased in recent years due to the costs connected to the installation and/or removal of pavement markings on low-volume roadways. Therefore, it is recommended that the safety impacts due to the installation of centerline/NPZ or centerline/NPZ and edgelines on both high-volume and low-volume roadways be further evaluated. There is a need for more reliable and robust CMFs related to the installation of basic pavement markings.

- The development of a secondary roadway pavement-marking database is recommended. This database could also include additional information about pavement-marking costs and any other characteristics that might be of value. This type of information could be part of a pavement-marking asset management program. The development of this database would assist with the evaluation of pavement-marking installation, maintenance costs, and potential safety impacts.

- The legal consideration or input provided to the project team about traffic control devices is generally common knowledge to counties in Iowa. The information provided focused on jurisdictional immunity and the maintenance of traffic control devices once they are installed. It is recommended that a committee be created to develop sample policies related to pavement-marking removal procedures. It is also recommended that this committee include a county attorney for the provision of legal advice on the sample policy.

- The MUTCD indicates that pavement markings that must be visible at night shall be retroreflective (unless lighted) (FHWA 2009). In addition, the guidance provided in the MUTCD is that "…unnecessary traffic control devices should be removed" (FHWA 2009). It also notes that "[m]arkings that are no longer applicable for roadway conditions or restrictions and that might cause confusion for the road user shall be removed or obliterated to be unidentifiable as a marking as soon as practical" (FHWA 2009). Some of the factors that might influence the impact of pavement markings might include, but are not limited to, their expected safety and operational benefits, percent no-passing zones, percentage of familiar and unfamiliar drivers, and car and truck or other slow-moving traffic volumes. The MUTCD provides some guidance about the removal of traffic signals and a previous research report from the Institute for Transportation (InTrans) addressed stop sign removal (FHWA 2009, Souleyrette et al. 2005). It is recommended that this information, and the input from the above committee, be used to develop policy content related to pavement-marking removal (e.g., a staged approach including, among other things, the use of engineering judgement/study, informing the public, staged traffic control, and observation/monitoring).

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APPENDIX A. TRAFFIC CONTROL DEVICES – UNDERSTANDING LIABILITY FROM THE PERSPECTIVE OF A MUNICIPALITY

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The State of Iowa, like the majority of states, offers certain protections to the State and municipalities relative to traffic control devices. Specifically, Iowa Code §668.10(1)(a) states:

1. In any action brought pursuant to this chapter, the state or a municipality shall not be assigned a percentage of fault for any of the following:

    a. The failure to place, erect, or install a stop sign, traffic control device, or other regulatory sign as defined in the uniform manual for traffic control devices adopted pursuant to section 321.252. However, once a regulatory device has been placed, created, or installed, the state or municipality may be assigned a percentage of fault for its failure to maintain the device (23).

Understanding the law surrounding this statute, and its application, is critical to municipalities. In its simplest interpretation, a municipality cannot be held liable for failing to place, erect or install traffic control devices, on any type of road, including low-volume, paved roadways . However, once the traffic control device has been installed, a municipality can be assigned fault if the municipality does not properly and adequately maintain the device.

The immunity granted to municipalities applies to all such placements or installation and thus a claim that the municipality should have done more to warn motorists or should have installed more traffic control devices does not overcome the immunity. *McClain v. State*, 563 N.W.2d 600 (Iowa 1997).

It even applies when the state or local government creates a road hazard through its own maintenance or construction and fails to erect warning signs. *Foster v. City of Council Bluffs*, 456 N.W.2d 1 (Iowa 1990). Section 668.10(1)(a) immunity also applies to state contractors and subcontractors who comply with the State's plans and specifications and who are not negligent in performing the work. *McLain v. State*, 563 N.W.2d 600 (Iowa 1997).

However, there are three exceptions to this statutory immunity: (1) claims for failure to maintain a device; (2) claims for the installation of a misleading sign; and (3) claims that exigencies are such that ordinary care would require the state or municipality to warn of dangerous conditions

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by other than inanimate devices. *Hunt v. State*, 538 N.W.2d 659 (Iowa Ct. App. 1995); *Estate of Oswald v. Dubuque County*, 511 N.W.2d 637 (Iowa Ct. App. 1993).

Exception One – Failure to Maintain Device

The Court applied the first exception—failure to maintain a device—in overturning a district court's decision granting a county immunity for failure to have warning signs in place at a bridge repair site. *Estate of Oswald v. Dubuque County*, 511 N.W.2d 637 (Iowa Ct. App. 1993). In that case, the county road repair crew had originally placed warning signs in front of a bridge they had torn out, but the signs were later removed by unknown parties. *Id*. The Court held that the removal of the posted signs generated a fact question regarding whether the county had appropriately maintained the devices as required by Section 668.10. *Id*. Presumably, if no sign had been erected at all, the county would have been immune.

In a case where it was claimed that the state failed to monitor the effectiveness of its warning signs, the court said that such monitoring "relates solely to the State's ultimate decision of whether or not to erect *additional* warning signs," and therefore the statutory immunity applied. *McLain v. State*, 563 N.W.2d 600 (Iowa 1997). The court further stated "Failure to monitor only invokes the maintenance exception when the monitoring involves signs that have already been placed, erected, or installed." *Id*. *See also Saunders v. Dallas County*, 420 N.W.2d 468, 472 (Iowa 1988) ("No matter how the challenged county activity is defined or labeled, it comes down to a choice of whether or where to place signs. A decision whether to replace this sign, to move it, or to supplant it with one or more other signs, is not a matter of maintenance under the statute. On the contrary such an action is a matter of deciding to place signs, for which the county cannot be held liable."). Also, if the issue boils down to whether the county should have placed or installed different signage to warn motorists, then the county is within the statutory immunity provision of section 668.10(1). *Mehlberger v. Johnson County, Iowa*, 2015 WL 1063056 (Iowa Ct. App. March 11, 2015).

Exception Two – Installation of a Misleading Sign

This exception has frequently been attacked by plaintiffs, however, the only successful challenge involved a blatant mistake by a county government, placing a right turn sign on a road that turned left. 11 Ia. Prac., Civil & Appellate Procedure Section 15.94 (2014 ed.); *See generally Sullivan v. Wickwire*, 476 N.W.2d 69 (Iowa 1991); *Phillips v. City of Waukee*, 467 N.W.2d 218 (Iowa 1991); *Saunders v. Dallas County*, 420 N.W.2d 468 (Iowa 1988). The government was found immune when a "Be Alert for Fog" sign provided no other instructions to the motorist on what to do in the event of fog. *Sullivan*, 476 N.W.2d 69. Placement of a "Crossroad Ahead" sign, instead of a "Yield Ahead" sign was also found not to be misleading, therefore, squarely within the government's immunity. *Phillips*, 467 N.W.2d 218. The rationale the court applied in these cases was that if the sign placement is done as the government intended, the immunity will apply to bar suit. 11 Ia. Prac., Civil & Appellate Procedure Section 15.94 (2014 ed.). However, if a mistake is made in carrying out the government's intention, e.g., placing a right turn sign on a left curve, no immunity will apply. *Saunders*, 420 N.W.2d 468.

Exception Three – Exigencies Require Warning with Other than Inanimate Devices

A government may be exempt from liability for failure to post signs, but recent decisions have suggested the possibility that courts may look to see if other duties have been violated that might trigger liability. 11 Ia. Prac., Civil & Appellate Procedure Section 15.95 (2014 ed.). In *Collister v. City of Council Bluffs*, 534 N.W.2d 453 (Iowa 1995) the defendant argued that Iowa Code Ann. § 668.10 immunized the city against a tort claim which resulted when a city employee left a disabled street sweeper in the middle of the road without warning lights or signs. The city claimed that under Iowa Code Ann. § 668.10, the city employee was not required to post signs or provide notice of the street sweeper to motorists. *Collister*, 534 N.W.2d 453. The Court dismissed the city's argument concluding that the posting of signs or traffic control devices was not a part of the complaint and that operators of city vehicles had the same duty to comply with the rules of the road as other drivers. *Id*; *See also McLain v. State*, 563 N.W.2d 600 (Iowa 1997) (no evidence to suggest that construction project was particularly unusual or that anything other than signs, such as a flagger, were needed).

Iowa Code §668.10(1)(a) has also been challenged and upheld on constitutional grounds. The Iowa Supreme Court did find that the application of this statute does not deprive a plaintiff of equal protection, due process or property rights. See *Phillips v. City of Waukee*, 467 N.W.2d 218 (Iowa 1991).

APPENDIX B. COUNTY SURVEY QUESTIONS

The Iowa Local Technical Assistance Program (LTAP) is investigating the use of pavement marking on low volume roadways (<= 400 vpd) in Iowa and surrounding states. Your input to this effort is requested. Please complete the following 6 questions about your pavement marking program. It is estimated to take less than 5 minutes. Please return your completed survey to sstruble@iastate.edu.

1. Please Enter the Name of your County

2. What pavement markings do you use on these roadway surfaces?

    a. Paved (HMA & PCC) Centerline/NPZ Only Centerline and Edgelines

    b. Seal Coat Centerline/NPZ Only Centerline and Edgelines

3. What is the approximate percentage of paved (HMA & PCC) county roadway that you paint with the following?

    a. Centerline/NPZ Only (100% to 0% in 25% increments)

    b. Centerline/NPZ and Edgeline (100% to 0% in 25% increments)

    c. Other (please specify)

4. If not all of your paved (HMA and PCC) roadways have pavement markings, what criteria do you use to select those you do paint (you may pick more than one)?

    a. Roadway Classification

    b. Pavement Width

    c. Traffic Volume

    d. Other (please specify)

5. What is the approximate percentage of seal coat county roadway that you paint with the following?

    a. Centerline/NPZ Only (100% to 0% in 25% increments)

b. Centerline/NPZ and Edgeline (100% to 0% in 25% increments)

c. Other (please specify)

6. If not all of your seal coat roadways have pavement markings, what criteria do you use to select those you do paint (you may pick more than one)?

    a. Roadway Classification

    b. Pavement Width

    c. Traffic Volume

    d. Other (please specify)

7. How often do you replace your pavement markings? [Drop down selection boxes with 2, 3 or 4 years and "other.]

a. Paved (HMA & PCC)	Centerline/NPZ	Centerline and Edgelines
b. Seal Coat	Centerline/NPZ	Centerline and Edgelines

8. How much would you estimate it costs per station for your pavement markings?