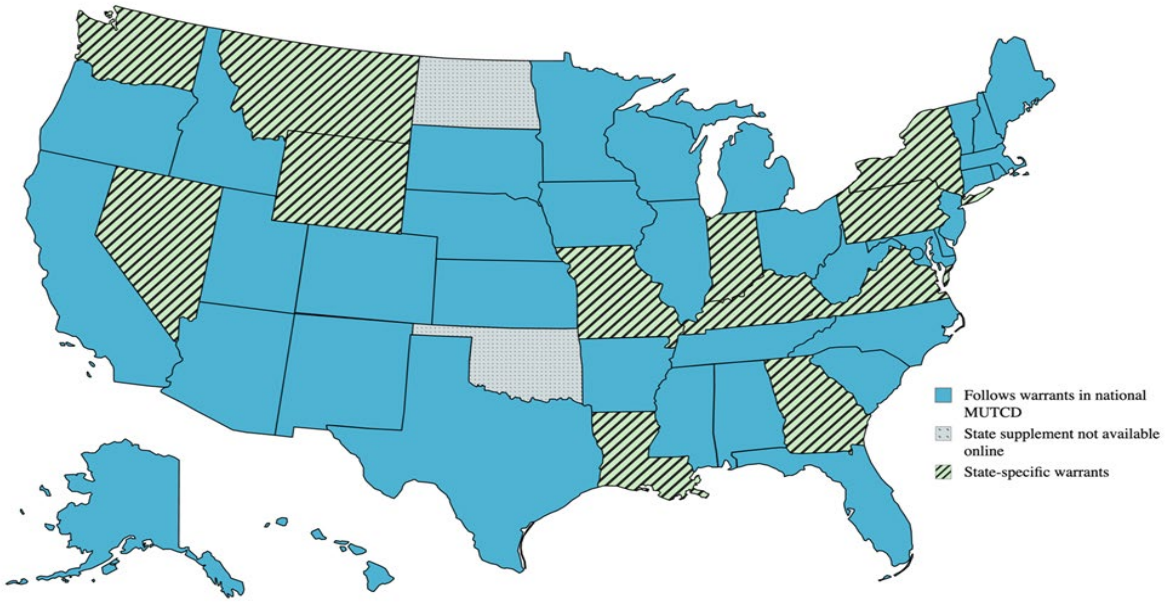
Striping Program



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Final Report

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16. Abstract

The use of wider (greater than 4 in) edge line pavement markings is recognized as a proven safety countermeasure by the Federal Highway Administration (FHWA). However, providing wider edge lines can pose challenges due to budget and striping capacity constraints. One strategy that could be used to address the capacity constraints involves reducing the amount of striping performed on low volume roads. The objective of this research study is to synthesize existing research and DOT practices regarding the use of wider edge line markings on all roads and the use of pavement markings of any width on low volume roads to facilitate the evaluation of tradeoffs between different pavement marking strategies. The research methodology to meet these objectives includes a literature review (e.g., research studies and DOT guidance and standards) and department of transportation (DOT) interviews. Results from the literature review indicate crash reductions for wider pavement markings ranging from 7 percent to 30 percent (total crashes) and from 14 percent to 51 percent (fatal and injury crashes) and benefit-cost ratios ranging from 24:1 to 55:1. Regarding prevalence of wider pavement markings, most state DOTs use 6-in markings (or, in some cases, 5-in markings) to some extent. Previous research studies on the use of pavement markings on low volume or narrow roads have shown mixed results. The literature review identified 12 state DOTs with state-specific warrants for center line or edge line markings on low volume roads. Implementation challenges noted by DOTs during the interviews include communication, budget and capacity constraints, and equipment needs. Overall, the research findings indicate that increased use of wider pavement markings and reductions in the use of pavement markings on lower volume roads is a viable strategy that can be explored further for implementation.

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Striping Program

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Final Report

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List of Abbreviations and Acronyms

23 CFR 420	Code of Federal Regulations, Title 23, Part 420
AADT	annual average daily traffic
ADT	average daily traffic
Caltrans	California Department of Transportation
CMF	crash modification factor
DOT	department of transportation
EPG	Engineering Policy Guide
FHWA	Federal Highway Administration
GDOT	Georgia Department of Transportation
MDOT	Michigan Department of Transportation
MnDOT	Minnesota Department of Transportation
MoDOT	Missouri Department of Transportation
MUTCD	Manual of Uniform Traffic Control Devices
NHDOT	New Hampshire DOT
PennDOT	Pennsylvania Department of Transportation
PSC	Proven Safety Countermeasure
TAC	Technical Advisory Committee
vpd	vehicles per day
WisDOT	Wisconsin Department of Transportation

Abstract

The use of wider (greater than 4 in) edge line pavement markings is recognized as a proven safety countermeasure by the Federal Highway Administration (FHWA). However, providing wider edge lines can pose challenges due to budget and striping capacity constraints. One strategy that could be used to address the capacity constraints involves reducing the amount of striping performed on low volume roads. The objective of this research study is to synthesize existing research and DOT practices regarding the use of wider edge line markings on all roads and the use of pavement markings of any width on low volume roads to facilitate the evaluation of tradeoffs between different pavement marking strategies. The research methodology to meet these objectives includes a literature review (e.g., research studies and DOT guidance and standards) and department of transportation (DOT) interviews. Results from the literature review indicate crash reductions for wider pavement markings ranging from 7 percent to 30 percent (total crashes) and from 14 percent to 51 percent (fatal and injury crashes) and benefit-cost ratios ranging from 24:1 to 55:1. Regarding prevalence of wider pavement markings, most state DOTs use 6-in markings (or, in some cases, 5-in markings) to some extent. Previous research studies on the use of pavement markings on low volume or narrow roads have shown mixed results. The literature review identified 12 state DOTs with state-specific warrants for center line or edge line markings on low volume roads. Implementation challenges noted by DOTs during the interviews include communication, budget and capacity constraints, and equipment needs. Overall, the research findings indicate that increased use of wider pavement markings and reductions in the use of pavement markings on lower volume roads is a viable strategy that can be explored further for implementation.

Executive Summary

Run-off-road crashes are a significant safety concern for highway agencies. In Missouri, there were 1,194 fatalities from run-off-road crashes between 2016 and 2018 (Missouri Coalition for Roadway Safety 2023). Pavement markings, especially edge line markings, can help to reduce the potential for run-off-road crashes by delineating the travel path for drivers.

One important consideration for pavement markings involves marking width. The newly released 11th Edition of the Manual on Uniform Traffic Control Devices (MUTCD) indicates that normal width markings should be 4 in to 6 in wide but recommends the use of 6-in markings to improve safety performance (FHWA 2023).

While the Missouri Department of Transportation (MoDOT) utilizes 6-in markings (except for center line markings on two-lane highways) on major highways (5,500 miles), it currently uses 4-in markings for minor routes (MoDOT 2017). MoDOT is considering expanding the use of 6-in markings to include minor routes but has concerns regarding the effects of this change on striping capacity. Due to increased time to refill paint, the use of 6-in edge lines is anticipated to reduce MoDOT's striping capacity by 8 miles per day per striping crew and 12,000 miles per year overall. Due to costs, lead time of equipment, and staffing shortages, MoDOT is unable to increase its overall striping capacity. Therefore, to provide the capacity to switch to 6-in edge lines on minor routes, MoDOT would need to reduce striping on other roadways, likely by eliminating center line striping on its 12,500 miles of low volume roads. MoDOT would like additional information to facilitate decision-making regarding a change from 4-in edge lines to 6-in edge lines on two-lane highways and the potential elimination of center line striping on low volume roads.

The objective of this research study is to synthesize existing research to identify safety benefits of wider edge lines, correlations between these safety benefits and annual average daily traffic (AADT), safety impacts of using center line markings on low volume roads, and any existing crash modification factors (CMFs) related to the use of wider edge lines on all roads and center line markings on low volume roads. Attainment of the project objectives will help MoDOT to evaluate the tradeoffs between different pavement marking strategies.

The research methodology to meet these objectives includes a literature review and department of transportation (DOT) interviews. The review of existing literature encompassed pavement marking width and the use of pavement markings on low volume roads, including research studies and DOT guidance and standards (e.g., state MUTCDs or MUTCD supplements, standard drawings, and standard specifications). Interviews were conducted with seven state DOTs regarding their practices for pavement marking width and the use of pavement markings on low volume roads.

A review of previous research studies on the safety performance of wider pavement markings indicates that, while some of the older studies showed inconsistent and inconclusive research findings, more recent research (2011 to 2023) has shown safety benefits associated with the use of wider pavement markings. Research studies have shown crash reductions for wider pavement markings ranging from 7 percent to 30 percent (total crashes) and from 14 percent to 51 percent (fatal and injury crashes) and benefit-cost ratios ranging from 24:1 to 55:1.

Other research studies related to pavement marking width have investigated agency practices, human factors, and considerations for automated vehicles. Results from human factors studies have shown

mixed results regarding the effects of marking width on lane position and encroachment (Miles et al. 2010, Abdel-Rahim et al. 2018). In addition, limited research has shown that wider pavement markings (6 in) outperformed 4-in markings with respect to machine vision detection, especially at longer distances (Davies 2017). However, the literature review did not identify any research regarding considerations for pavement marking width based on striping capacity constraints.

A review of DOT guidance (e.g., state MUTCDs, state MUTCD supplements, pavement markings guidance) and standards (e.g., standard drawings, standard specifications) indicates that most state DOTs use 6-in markings (or, in some cases, 5-in markings) to some extent. Fourteen state DOTs utilize 4-in markings on freeways, while 11 state DOTs follow the national MUTCD guidance of 4-in to 6-in markings. In addition, three state DOTS (Alabama, Georgia, and Maryland) use a 5-in width for edge line and center line markings on freeways, while Nevada DOT uses 8-in markings on freeways (Alabama DOT 2022, Georgia DOT 2021, Maryland State Highway Administration 2011, Nevada DOT 2022). Other state DOTs use 6-in markings for certain types of roadways (e.g., interstates, freeways).

For non-freeways, 18 state DOTs utilize 4-in markings, while 11 state DOTs follow the national MUTCD guidance of 4-in to 6-in markings. Other state DOTs use 6-in markings for certain types of roadways (e.g., National Highway System) or roadways meeting minimum thresholds for Annual Average Daily Traffic (AADT) and/or speed.

Previous research studies on the use of pavement markings on low volume or narrow roads have shown mixed results. For example, a Louisiana study found a reduction in expected crashes of 15 percent with the use of edge lines on narrow two-lane roads, while a study in Virginia found no statistical difference in safety performance between low volume narrow roads with or without center lines or edge lines (Sun and Das 2014, Kweon et al. 2015). Other research indicated that the use of edge lines on narrow width roads helped drivers stay in their travel path but did not affect drivers' speeds (Sun and Tekell 2005).

The MUTCD includes requirements for center line markings for different facility types based on minimum thresholds for average daily traffic (ADT) and traveled way width (FHWA 2023). MoDOT's pavement marking guidelines state that major roads and regionally significant roads should be striped annually (MoDOT 2017). In addition, minor roads with AADTs of at least 400 vpd should be striped every other year, and minor roads with AADTs less than 400 vpd should be striped every three years.

A review of state DOT guidance and standards for use of pavement markings on low-volume roads found that 11 other state DOTs, besides MoDOT, have state-specific warrants for center line or edge line markings. These state-specific warrants go beyond the MUTCD warrants by lowering the ADT or width thresholds and are sometimes based on facility type.

Interviews were conducted with seven DOTs regarding their practices for using wider pavement markings and pavement markings on low volume roads. Criteria for selection included diversity with respect to geography, pavement marking width, and use of state-specific pavement marking warrants as well as feedback from the project Technical Advisory Committee (TAC).

Six of the seven DOTs that participated in the interviews use wider pavement markings (greater than 4 in.) to some extent. The extent of implementation of wider striping varies based on the type of line (e.g., edge line only or all lines) and type of roadway (e.g., interstate or other roadways). In some cases, the extent of implementation of wider striping varies between DOT districts. With respect to the timing of implementation, three of these seven DOTs have either switched to 6-in markings or have expanded

their use of 6-in markings since 2020. Two DOTs are planning to switch to 6-in markings in the future. DOTs that have switched to wider pavement markings have typically based the decision on the CMFs in the CMF Clearinghouse (FHWA 2024), anticipated changes to the MUTCD (FHWA 2023), and, in some cases, considerations for connected and automated vehicles. While the DOT interviewees that use wider markings have not observed any difference in service life, one DOT has observed that wider markings are more resistant to snowplow activity. Materials used for striping include waterborne paint, epoxy, ground-in high build latex, polyurea, thermoplastic, and tape.

The DOT interviewees also provided information regarding implementation challenges for wider striping and strategies to maximize production. Challenges that these DOTS have faced in changing to wider markings include communication across departments, getting agency buy-in, budget considerations, striping capacity, and changes in striping equipment or the need to purchase additional striping equipment. Some DOTs have been able to manage the increased cost of wider striping through additional funding or other means. In addition, some DOTs have had additional capacity to accommodate wider striping. However, two DOTs indicated that they would have to reduce striping on low volume roads to accommodate an expansion of wider striping. These DOTs utilize various strategies to help maximize production while maintaining quality, such as grouping projects into longer segments, working with striping crews to improve quality, working extended hours, employing advanced equipment, and exploring new technologies and materials.

As noted in the DOT interviews, practices for applying striping on low volume roads include striping all roads (especially if the quantity of low volume roads under DOT jurisdiction is minimal), striping roads above minimum thresholds for width and/or AADT, and prioritizing roads for striping based on categories. In some cases, higher volume roads are striped more frequently. Practices for applying striping on low volume roads sometimes vary between districts of a given DOT.

Overall, the existing research provides more support for the use of wider pavement markings than for the use of pavement markings on low volume roads. Given these findings, MoDOT could explore the use of 6-in markings on minor routes and the elimination of pavement markings on some low volume roads. MoDOT could also consider a hybrid approach, such as the use of 5-in edge lines on other routes and the development of warrants for center line markings on low volume roads based on AADT, width, and/or speed. Based on the experiences of other DOTs, important considerations for the use of wider pavement markings include striping capacity, budget constraints, and equipment needs. MoDOT could also explore strategies to help maximize striping production, such as grouping projects into longer segments, employing advanced equipment, and new technologies and materials.

1. Introduction

In Missouri, there were 1,194 fatalities from run-off-road crashes between 2016 and 2018 (Missouri Coalition for Roadway Safety 2023). Pavement markings, especially edge line markings, can help to reduce the potential for run-off-road crashes by delineating the travel path for drivers.

Guidance regarding the use of pavement markings is provided in the Manual of Uniform Traffic Control Devices (MUTCD). The newly released 11th Edition MUTCD indicates that normal width markings should be 4 in to 6 in wide but recommends the use of 6-in markings to improve safety performance (FHWA 2023).

While Missouri Department of Transportation (MoDOT) utilizes 6-in markings (except for center line markings on two-lane highways) on major highways (5,500 miles), it currently uses 4-in markings for minor routes (MoDOT 2017). MoDOT is considering expanding the use of 6-in markings to include minor routes. MoDOT is considering expanding the use of 6-in markings to include minor routes but has concerns regarding the effects of this change on striping capacity. Due to increased time to refill paint, the use of 6-in edge lines is anticipated to reduce MoDOT's striping capacity by 8 miles per day per striping crew and 12,000 miles per year overall. Due to costs, lead time of equipment, and staffing shortages, MoDOT is unable to increase its overall striping capacity. Therefore, to provide the capacity to switch to 6-in edge lines on minor routes, MoDOT would need to reduce striping on other roadways, likely by eliminating center line striping on its 12,500 miles of low volume roads. MoDOT would like additional information to facilitate decision-making regarding a change from 4-in edge lines to 6-in edge lines on two-lane highways and the potential elimination of center line striping on low volume roads.

Project Objective

The objective of this research study is to synthesize existing research to identify safety benefits of wider edge lines, correlations between these safety benefits and annual average daily traffic (AADT), safety impacts of using center line markings on low volume roads, and any existing crash modification factors (CMFs) related to the use of wider edge lines on all roads and center line markings on low volume roads. The research methodology to meet these objectives includes a literature review and department of transportation (DOT) interviews. Attainment of the project objectives will help MoDOT to evaluate the tradeoffs between different pavement marking strategies.

Report Overview

This report provides a summary of the literature review conducted for this project, including research studies and DOT guidance and standards. In addition, the report summarizes the interviews that were conducted with other DOTs. The final chapter of the report provides a summary of key research findings. Appendices include a tabular literature summary and interview questions.

2. Literature Review

This chapter provides an overview of the existing literature regarding pavement marking width and the use of pavement markings on low volume roads, including research studies and DOT guidance and standards (e.g., state MUTCDs or MUTCD supplements, standard drawings, and standard specifications). Tabular summaries of existing literature are provided in Appendix A.

Review of Literature Regarding Pavement Marking Width

Research Studies on Pavement Marking Width

A review of previous research studies on the safety performance of wider pavement markings indicates that, while some of the older studies showed inconsistent and inconclusive research findings, more recent research has shown safety benefits associated with the use of wider pavement markings. In addition, the Federal Highway Administration (FHWA) recognizes wider edge lines as a proven safety countermeasure (PSC) (Albee and Bobitz, 2021). Other research studies related to pavement marking width have investigated agency practices, human factors, and considerations for automated vehicles. However, the literature review did not identify any research regarding considerations for pavement marking width based on striping capacity constraints.

Several studies regarding the use of 8-in-wide edge lines were conducted in the 1980s, with mixed results. Cottrell (1987) investigated the impacts of 8-in wide edge lines on run-off-road and other related crashes on two-lane highways in Virginia using two statistical methods: before-after with comparison group and Gart's procedure. Results indicated that the use of 8-in-wide edge lines resulted in no statistically significant reductions in run-off-road crashes. Hall (1987) assessed the safety effects of using 8-in wide edge lines on rural two-lane highways in New Mexico based on the before-after with comparison group method. Findings indicated that the 8-in-wide edge lines resulted in no statistically significant difference in run-off-road crashes, including run-off-road crashes at night or on horizontal curves and crashes involving the opposing traffic lane. Hughes et al. (1989) investigated the safety effects of 8-in wide edge lines on rural two-lane highways using data from seven states and the before-after with comparison group method. Findings indicated that, compared with 4-in-wide edge lines, 8-in-wide edge lines did not reduce crash frequency on roads with AADT ranging from 5,000 to 10,000 vehicles per day (vpd). The authors concluded that the 8-in wide edge line markings could be cost effective for the following conditions: AADT between 2,000 and 5,000 vpd, high frequency of rainfall, and pavement widths of 24 ft and unpaved shoulders.

Results from more recent studies, including one conducted in Missouri, have generally shown crash reductions associated with the use of wider pavement markings. Potts et al. (2011) conducted an evaluation of the safety performance of wider pavement markings using Missouri data from the Smooth Roads Initiative with the Empirical Bayes before-after method. The use of wider markings without resurfacing was associated with a 22.4-percent reduction in fatal and injury crashes on rural freeways and a 50.8-percent crash reduction in fatal and injury crashes on urban freeways. The benefit-cost ratio of wider markings without resurfacing was calculated as 23.8 for rural freeways and 28.5 for urban freeways.

Regarding studies in other states, Park et al. (2012) analyzed crash frequency data for Kansas, Michigan, and Illinois using Empirical Bayes before-after and cross-sectional methods to assess the safety effects of wider edge lines. Results indicated crash reductions of 17.5 percent to 30.1 percent (total crashes) and

15.4 percent to 37.7 percent (fatal plus injury crashes). Results from an Empirical Bayes before-after safety analysis of data from Michigan showed crash reductions of 7.1 percent (all crashes) and 17.1 percent (fatal injury crashes) (Miles et al. 2010). Research performed by Abdel-Rahim et al. (2018) included the analysis of crash data (using before-after with comparison group and Empirical Bayes methods) for two-lane highways in Idaho. Results from the Empirical Bayes method indicated that wider pavement markings reduced the number of crashes by 17 percent and fatal and severe injury crashes by 14 percent. Crash rates were reduced by 5.53 percent (total crashes) and 12.59 percent (severe injury crashes). The benefit-cost ratio of wide pavement markings on Idaho two-lane highways was found to be approximately 1:25. Results also indicated that 6-in markings degrade at a slower rate than 4-in markings.

A research study conducted in Canada also noted crash reductions associated with the use of wider pavement markings. Utilizing data from 38 highway sites across British Columbia, Alberta, and Quebec over eight years, Hussein et al. (2020) employed a Full Bayes analytical approach. The findings indicated a significant reduction in collisions after implementation of wider markings, with total collisions decreasing by 12.3 percent and run-off-road collisions decreasing by 19.0 percent. The study found that total collisions decreased by 11.1 percent in Alberta, 27.5 percent in British Columbia, and 1.1 percent in Quebec.

A summary of crash reductions from prior research studies is found in Table 2-1. In addition, Table 2-2 summarizes the CMFs for wider pavement markings that are available in the CMF Clearinghouse (FHWA 2024). These CMFs show that wider pavement markings are associated with crash reductions, with a wide range of star quality ratings for the CMF values.

Table 2-1. Summary of crash reductions from previous studies on pavement marking width.

Location	Reference	Crash Reduction	Benefit-Cost Ratio
Idaho	Abdel Rahim et al. 2018	• 17 percent (total) • 14 percent (fatal and severe injury)	25:1
Kansas, Other states	Carlson and Wagner 2012	• 15 percent to 30 percent (total) • 15 percent to 38 percent (fatal plus injury)	33:1 to 55:1
Virginia (8-in markings)	Cottrell 1987	• No significant reduction found	-
New Mexico (8-in markings)	Hall 1987	• No significant reduction found	-
8 States (8-in markings)	Hughes et al. 1989	• No significant reduction found	-
Canada	Hussein et al. 2020	• 12.3 percent (total) • 19 percent (run-off-road)	-
Illinois, Michigan	Miles et al. 2010	• 7.1 percent (all crashes) • 17.1 percent (fatal injury crashes)	-
Illinois, Kansas, Michigan	Park et al. 2012	• 17 percent to 30 percent (total) • 15 percent to 38 percent (fatal plus injury)	-
Missouri	Potts et al. 2011	• 22.4 percent (fatal and injury, rural freeways) • 50.8 percent (fatal and injury, urban freeways)	• 23.8:1 (rural freeways) • 28.5:1 (urban freeways)

Table 2-2. Summary of CMF values for wider pavement markings (FHWA 2024).

Description	State or Province	Crash Severity	CMF Value	Star Quality Rating	Reference
4 in to 6 in	MO	All	0.78	2	Potts et al. 2011
4 in to 6 in	KS	All	0.825	4	Park et al. 2012
4 in to 6 in	KS	Fatal & injured	0.63	4	Park et al. 2012
4 in to 6 in	KS	PDO	0.877	4	Park et al. 2012
4 in to 5 in	IL	All	0.699	3	Park et al. 2012
4 in to 5 in	IL	Fatal & injured	0.623	3	Park et al. 2012
4 in to 5 in	IL	PDO	0.761	3	Park et al. 2012
4 in to 6 in	MI	All	0.806	3	Park et al. 2012
4 in to 6 in	MI	Fatal & injured	0.839	3	Park et al. 2012
4 in to 6 in	MI	PDO	0.804	3	Park et al. 2012
4 in to 6 in	ID	All	0.83	2	Mohamed et al. 2019
4 in to 6 in	ID	Fatal & injured	0.86	2	Mohamed et al. 2019
4 in to 6/8 in	Alberta, British Columbia, and Quebec	All	0.877	5	Hussein et al. 2020
4 in to 6/8 in	Alberta, British Columbia, and Quebec	Run off road	0.81	5	Hussein et al. 2020
4 in to 6/8 in	Alberta	All	0.889	5	Hussein et al. 2020
4 in to 6/8 in	Alberta	Run off road	0.711	4	Hussein et al. 2020
4 in to 6/8 in	British Columbia	All	0.725	5	Hussein et al. 2020
4 in to 6/8 in	British Columbia	Run off road	0.773	4	Hussein et al. 2020
4 in to 6/8 in	Quebec	All	0.989	3	Hussein et al. 2020
4 in to 6/8 in	Quebec	Run off road	0.751	3	Hussein et al. 2020

There has also been some limited research regarding wider pavement markings and human factors. Results from a human factors study conducted by Miles et al. (2010) showed that encroachment on the edge line on the inside of horizontal curves decreased as the edge line marking width increased. In addition, study participants stayed farther from the edge line on tangent sections with greater edge line marking widths. However, findings from a driving simulator study conducted by Abdel-Rahim et al. (2018) found that pavement marking width by itself did not influence lane position.

Other studies regarding wider pavement markings have focused on literature reviews and surveys. In their literature review, Carlson and Wagner (2012) noted wider edge lines have been associated with crash reductions of 15 percent to 30 percent (total crashes) and 15 percent to 38 percent (fatal plus

injury crashes). Results from an economic analysis of data performed by Carlson and Wagner (2012) using data from Kansas (Park et al. 2012) indicated benefit-cost ratios of 33:1 to 55:1.

The methodology for a study by Gates and Hawkins (2002) included agency surveys and a review of technical literature. The survey identified 29 state DOTs that use wider pavement markings to some extent. The researchers found a lack of conclusive data on crash reduction or extended service life associated with the use of wider markings. The researchers found that some agencies use indirect safety measures (e.g., driver opinion surveys and surrogate measures) to assess the performance of wider pavement markings. Agencies generally indicated that they were satisfied with the use of the wider markings. Researchers found that wider markings may offer significant benefits when applied in horizontal curves, narrow shoulders, work zones, areas with low luminance contrast, and where older drivers are predominant.

Results from a survey of state DOTs conducted by Obeng-Boampong et al. (2009) indicated that wider pavement markings are increasingly being used by states, with 76 percent of responding state DOTs implementing wider markings. The authors concluded that the increased usage of wider pavement markings seems to be driven more by subjective assessments and state policies. The primary implementation challenges were identified as cost and a lack of research on the safety benefits of wider pavement markings. States indicated that wider pavement markings are generally well received by the public. The authors identified a need for more objective research to conclusively determine the safety benefits of wider pavement markings.

A more recent research study looked at wider pavement markings and machine vision systems. Specifically, Davies (2017) conducted static testing of a stationary vehicle in a parking lot to understand the effects of pavement markings on the performance of machine vision systems. The results showed that wider pavement markings (6 in) outperformed 4-in markings with respect to machine vision detection, especially at longer distances. Findings also indicated that the wider markings may help to counter lower retroreflectivity and may lengthen the service life of the pavement markings.

Guidance and Standards for Pavement Marking Width

MUTCD Guidance and Standards for Pavement Marking Width

The 2009 edition of the MUTCD indicates that normal edge lines shall be 4 to 6 in wide, and wide solid edge line markings may be used for greater emphasis (FHWA 2009). The 2023 edition of the MUTCD also requires normal edge lines to be 4 to 6 in wide (FHWA 2023). However, the 2023 edition also includes supplemental language indicating that using wider edge lines at 6 in is optional but can offer greater emphasis and has shown improved safety at locations with a history of run-off-road crashes. In addition, the 2023 edition suggests that edge lines at least 6 in wide should be considered by agencies trying to improve infrastructure for automated vehicles with potential benefits also to human drivers.

MoDOT Guidance and Standards for Pavement Marking Width

MoDOT's current practices for pavement marking width include both 4-in and 6-in markings. A decision tree in the MoDOT Engineering Policy Guide (EPG), shown in Figure 2-1, indicates that white edge lines and center lines and yellow edge lines on all major routes should be 6 in wide and all other markings should be 4 in wide (MoDOT 2017). Marking materials should consist of high build waterborne paint with Type L beads for major routes and waterborne paint with Type P beads for other routes.

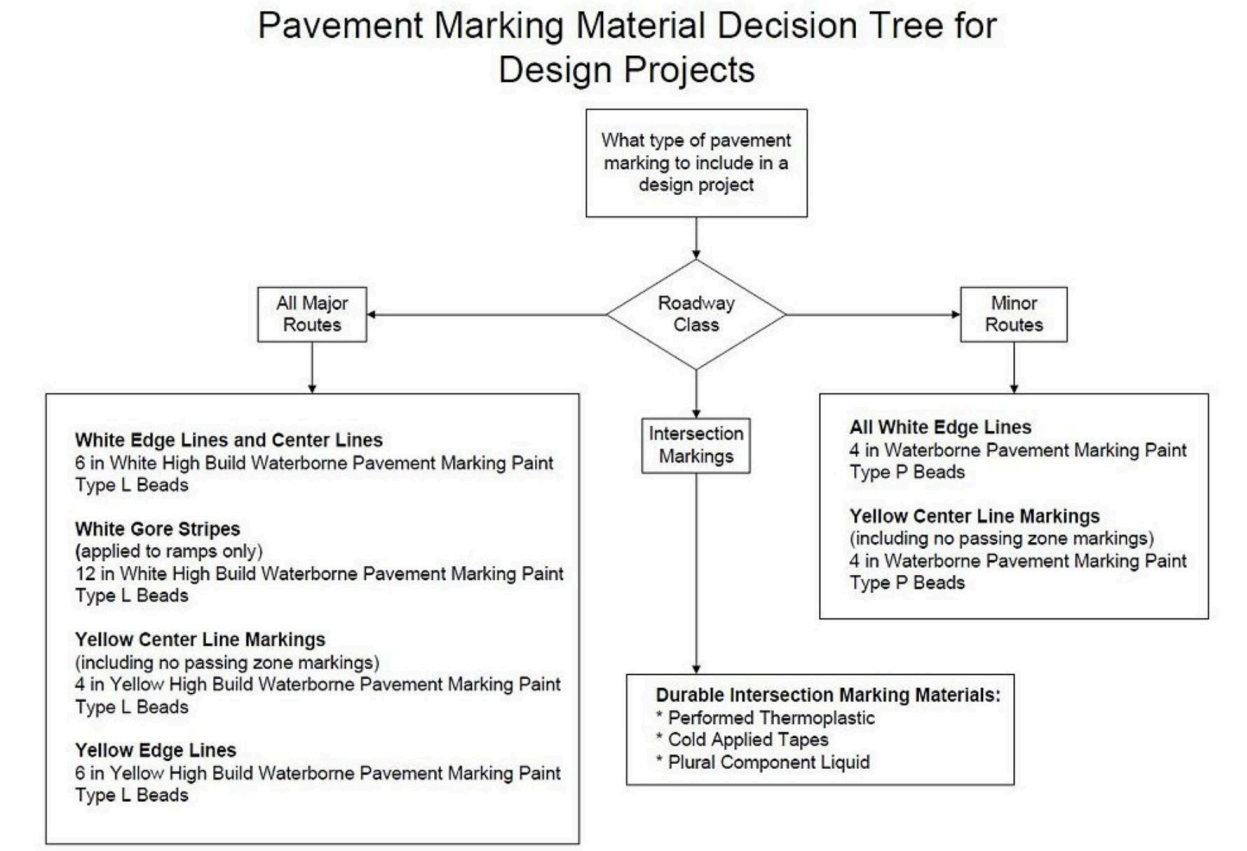

Figure 2-1. Pavement marking decision tree from MoDOT EPG (MoDOT 2017).

Guidance and Standards for Other State DOTs Regarding Pavement Marking Width

A review of DOT guidance (e.g., state MUTCDs, state MUTCD supplements, pavement markings guidance) and standards (e.g., standard drawings, standard specifications) indicates that most state DOTs use 6-in markings (or, in some cases, 5-in markings) to some extent. Figure 2-2 shows a map of pavement marking width by state DOT for freeways. As shown in the map, 14 state DOTs utilize 4-in markings on freeways, while 11 state DOTs follow the national MUTCD guidance of 4-in to 6-in markings. In addition, three state DOTS (Alabama, Georgia, and Maryland) use a 5-in width for edge line and center line markings on freeways, while Nevada DOT uses 8-in markings on freeways (Alabama DOT 2022, Georgia DOT 2021, Maryland State Highway Administration 2011, Nevada DOT 2022). Other state DOTs use 6-in markings for certain types of roadways. For example, Maine DOT and New Hampshire DOT (NHDOT) specify 6-in markings for Interstates, while Indiana DOT uses 6-in markings for DOT roadways and 4-in markings for local public agency roadways (Maine DOT 2020b, New Hampshire DOT 2016, Indiana DOT 2022). Guidance provided in the Ohio Traffic Engineering Manual indicates that edge line markings on interstates, freeways and expressways, multilane divided highways, multilane undivided highways, and two-lane rural highways should be 6 in wide, while edge line markings on other types of roadways and center line markings should be 4 in wide (Ohio DOT 2024).

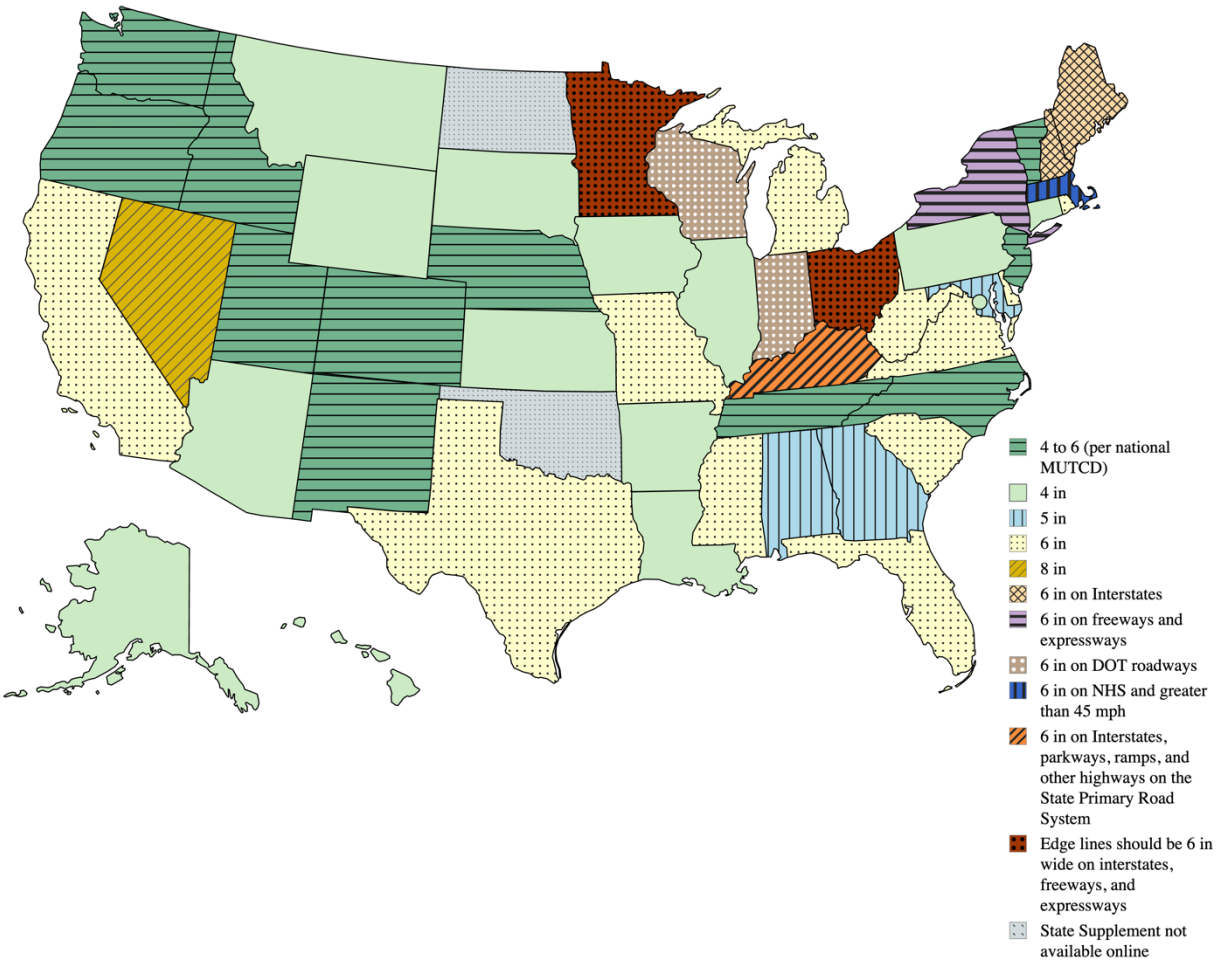

Figure 2-2. Map showing pavement marking width by state DOT for freeways (Map created with mapchart.net).

Figure 2-3 shows a map of pavement marking width by state DOT for non-freeways. As shown in the map, 18 state DOTs utilize 4-in markings on non-freeways, while 11 state DOTs follow the national MUTCD guidance of 4-in to 6-in markings. Alabama DOT, Georgia DOT, and Maryland DOT also use 5-in markings for non-freeways (Alabama DOT 2022, Georgia DOT 2021, Maryland State Highway Administration 2011). Other state DOTs use 6-in markings for certain types of roadways. For example, Massachusetts DOT uses 6-in markings for roadways on the National Highway System (NHS) with speeds of 45 mph or higher (Massachusetts DOT 2022). Nevada DOT applies 6-in edge line striping for rural roadways with an AADT higher than 400 vpd, for rural roadways with speeds exceeding 40 mph, and for a list of specified state routes (Nevada DOT 2022).

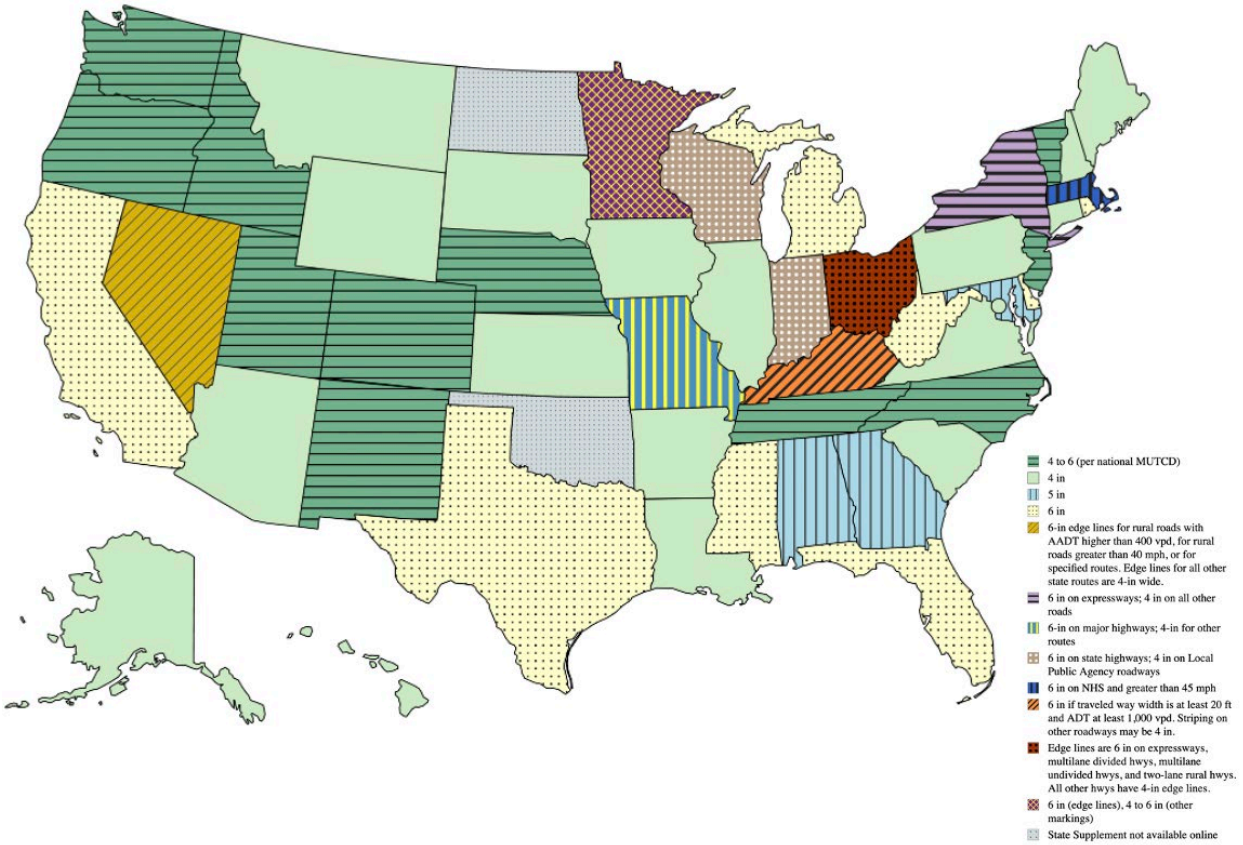

Figure 2-3. Map showing pavement marking width by state DOT for non-freeways (Map created with mapchart.net).

Various DOTs are in the process of switching to 6-in markings, and the timeline and extent of these implementations differ among the DOTs. For example, the Michigan Department of Transportation (MDOT), which uses 6-in markings on state trunklines, proceeded with a switch to 6-in markings on freeways in 2020 and began the transition to 6-in markings on non-freeways in 2021 (Michigan DOT 2024). The Minnesota Department of Transportation (MnDOT) only requires the 6-in width for edge lines installed in 2022 or later (Minnesota DOT 2023b).

Review of Literature Regarding Use of Pavement Markings on Low Volume Roads

Research Studies on Use of Pavement Markings on Low Volume Roads

Previous research studies on the use of pavement markings on low volume or narrow roads have shown mixed results. Some studies have evaluated the use of pavement markings on low volume roads based on surrogate measures such as traffic conflicts or travel path deviation. For example, Stockton et al. (1976) applied probability of conflict analyses to assess the need for pavement markings on segments with inadequate passing sight distance on low volume (average daily traffic (ADT) less than 400 vpd) rural roads. The results showed no benefit to the use of striping at these locations due to the low probability of a conflict. As an alternative, Stockton et al. (1976) suggested the use of a PASSING HAZARDOUS sign or double narrow lane marking (1.5-in lines with 1-in space). A research study by Sun

and Tekell (2005) included a field evaluation for the use of edge lines on Louisiana roads with a narrow width (20 ft to 22 ft). Results showed that edge lines helped drivers stay in their travel path but did not affect drivers' speeds. While calculating crash reductions was outside the scope of the study, Sun and Tekell (2005) indicated that the magnitude of the safety impact of wider edge lines on rural two-lane highways varies based on factors such as roadway width, operating speed, time of day, percent of heavy vehicles, pavement condition, roadway alignment, and opposite direction traffic.

Follow-up studies were conducted in Louisiana to further evaluate the effects of wider edge lines on narrow roads. Sun and Das (2012) applied a before-after safety analysis to assess the safety impacts of edge lines on narrow (less than 22 ft) rural two-lane highways in Louisiana. Three years of before crash data and one year of after crash data were used. Results showed a reduction in expected crashes of 17 percent with the use of edge lines. In subsequent research, Sun and Das (2014) utilized the Empirical Bayes method to assess the safety impacts of edge lines on narrow (pavement width greater than or equal to 20 ft and less than 22 ft) rural two-lane highways in Louisiana. Three years of before crash data and three years of after crash data were used. As shown in Figure 2-4, ADT values ranged between 0 and 10,000 vpd. Results showed a reduction in expected crashes of 15 percent with the use of edge lines. A benefit-cost ratio of 19:1 was estimated. Sun and Das (2014) suggested the prioritization of roadways with higher volumes if financial or operational constraints exist.

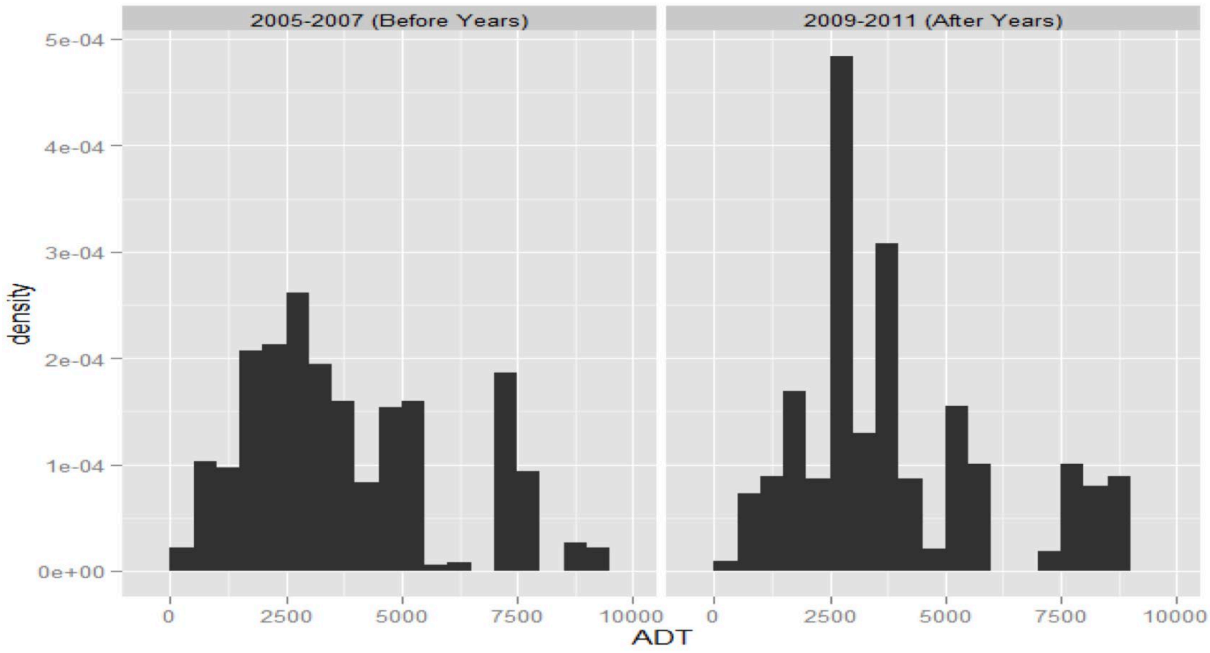

Figure 2-4. ADT density of Louisiana study segments in before and after periods (Sun and Das 2014).

Results from research conducted in other states did not find significant crash reductions associated with the use of pavement markings on low volume roads. The methodology for a study by Glennon (1984) consisted of a survey and analysis of traffic and crash data for low volume (less than 400 vpd) two-lane rural roads under the federal Pavement Marking Demonstration program. Results showed that the use of center line markings did not appear to reduce crash rates. Warrants for center line markings were developed based on road width and ADT (e.g., 500 vpd for roadway width greater than 20 ft). A study by Kweon et al. (2015) included the evaluation of five years of crash data on low volume (3,000 vpd or less) narrow (20 ft or less) roads in Virginia. The following four marking configurations were studied: no

markings, center line markings only, edge line markings only, and both center line and edge line markings. Results indicated that there was no statistical difference in safety performance between low volume narrow roads with or without center lines or edge lines.

Other literature has focused on agency practices for the use of pavement markings on low volume roads in Minnesota and Iowa. Veneziano and Smadi (2018) provided an overview of pavement marking practices in Minnesota and highlighted the need for a systematic approach to prioritize pavement markings on local roadways, especially considering budget constraints and safety benefits. They developed a spreadsheet tool to facilitate the evaluation and prioritization of various pavement marking alternatives, including center lines only, edge lines only, both center lines and edge lines, high-visibility markings, and enhanced durability markings. The developed tool was based on current practices and policies, with a goal of aiding in decision-making for pavement marking installations. The objective of a study by Knapp et al. (2015) was to assess the state of the practice for the use of pavement markings on low volume roads in Iowa through a literature review, survey of Iowa county engineers, and benefit-cost analysis. Survey results indicated that 97 percent of respondents used painted center lines and edge lines to some extent on low volume roads. Results from the benefit-cost analysis showed that a crash reduction of 5.1 percent would make the use of pavement markings on low volume roads beneficial.

Guidance and Standards for Use of Pavement Markings on Low Volume Roads

MUTCD Guidance and Standards for Use of Pavement Markings on Low Volume Roads

As noted in the 2009 edition of the MUTCD, center line markings must be provided on all paved urban arterials and collectors with a traveled way width of at least 20 ft and ADT of at least 6,000 vpd (FHWA 2009). Center line markings are also required on all paved two-way streets or highways with at least three lanes of vehicular traffic. In addition, the use of center line markings is suggested for paved urban arterials and collectors with a traveled way of at least 20 ft and ADT of at least 4,000 vpd, for rural arterials and collectors with a traveled way width of at least 18 ft and ADT of at least 3,000 vpd, and at other locations deemed necessary by an engineering study. However, the MUTCD notes that engineering judgment should be exercised to assess the need for center line markings on traveled ways with a width less than 16 ft due to the possibility of traffic encroachment on the opposing lane or pavement edges or effects of parked vehicles.

The 2023 edition of the MUTCD does not include any changes to the warrants for center line markings (FHWA 2023).

MoDOT Guidance and Standards for Use of Pavement Markings on Low Volume Roads

MoDOT's pavement marking guidelines state that major roads and regionally significant roads should be striped annually, unless retroreflectivity exceeds requirements for new pavement markings (MoDOT 2017). Minor roads with AADTs of at least 400 vpd should be striped every other year, and minor roads with AADTs less than 400 vpd should be striped every three years.

Guidance and Standards for Other State DOTs for Use of Pavement Markings on Low Volume Roads

State DOT guidance and standards for use of pavement markings on low-volume roads were reviewed. As shown in Figure 2-5, the literature review identified 11 other state DOTs, besides MoDOT, with state-specific warrants for center line or edge line markings. These state-specific warrants, which are summarized in Table 2-3, go beyond the MUTCD warrants by lowering the ADT or width thresholds and are sometimes based on facility type. Some examples are highlighted below:

- The Indiana Design Manual recommends center line markings on paved, non-DOT roadways with ADT at least 300 vpd (Indiana DOT 2022).
- As described in guidance from the Kentucky Transportation Cabinet, pavement marking warrants are based primarily on traveled way width. Center line markings are not utilized on roadways with a traveled way width less than 16 ft (Commonwealth of Kentucky Transportation Cabinet 2021). However, edge line markings should be provided unless division approval is received to omit them. For two-lane highways with traveled way widths greater than or equal to 16 ft and less than 20 ft, edge line markings should be provided unless division approval is received to omit them. Either center line or edge line striping should be provided based on engineering judgement. For two-lane highways with a traveled way width of at least 20 ft, center line markings are required. Edge line markings are also required if the ADT is at least 1,000 vpd. Edge line markings are not required if the ADT is less than 1,000 vpd and the roadway is not on the SPRS.
- Virginia DOT (2013) requires center line markings for all undivided limited access highways, bi-directional multi-lane roadways, and all other paved roadways (excluding residential streets) with a pavement width of at least 18 ft and ADT of at least 500 vpd. Virginia DOT's warrants for center line markings are shown in Table 2-4.
- Georgia DOT (2023b) requires edge lines on all paved roadways.

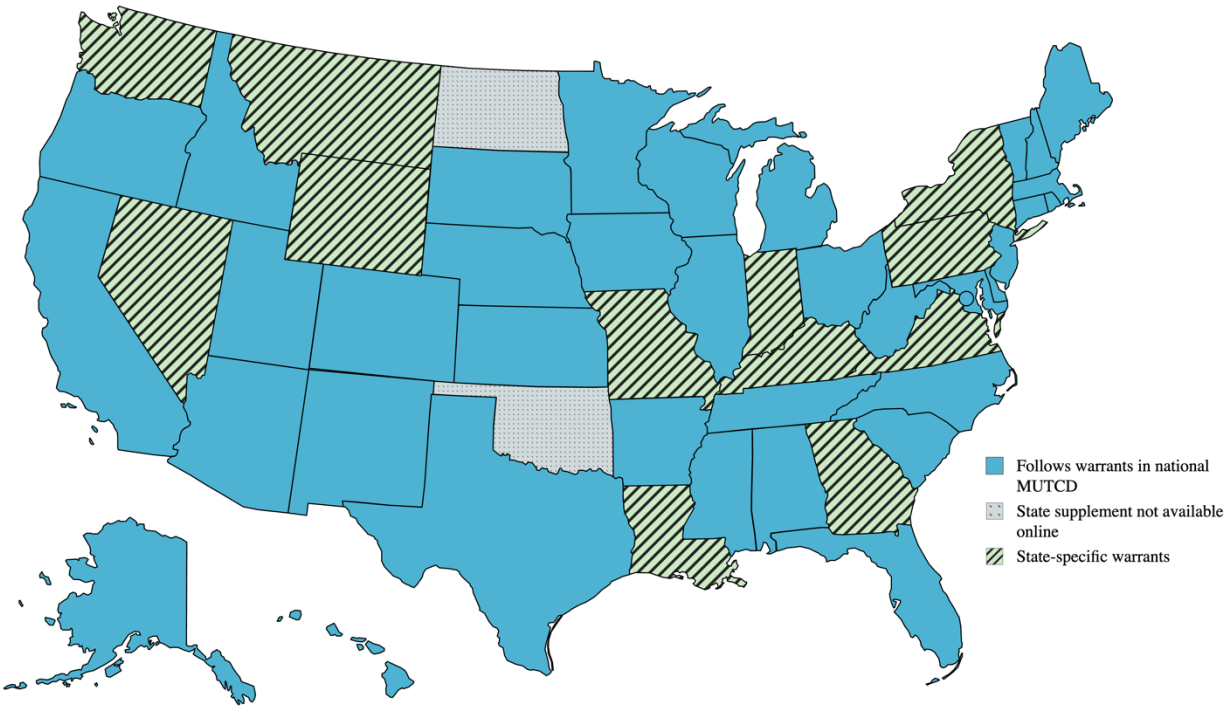

Figure 2-5. Map showing use of state-specific warrants for pavement markings by state DOT (Map created with mapchart.net).

Table 2-3. Summary of state-specific warrants for pavement markings.

State	Pavement Marking Warrant
Georgia	Edge lines required on all paved roadways (Georgia DOT 2023b).
Indiana	Center line markings recommended on paved, non-DOT roadways with ADT at least 300 vpd (Indiana DOT 2022).

State	Pavement Marking Warrant
Kentucky	Warrants are based primarily on traveled way width. For two-lane two-way roadways with traveled way widths less than 16 ft, center lines should not be placed. However, edge line markings should be provided unless division approval is received to omit them. For two-lane highways with traveled way widths greater than or equal to 16 ft and less than 20 ft, edge line markings should be provided unless division approval is received to omit them. Either center line or edge line markings should be provided based on engineering judgement. For two-lane highways with a traveled way width of at least 20 ft, center line marking is required. Edge line markings are also required if the ADT is at least 1,000 vpd. Edge line markings are not required if the ADT is less than 1,000 vpd and the roadway is not on the SPRS (Commonwealth of Kentucky Transportation Cabinet 2021).
Louisiana	Center line markings should be installed on roadways with a traveled way width of at least 16 ft. Edge line markings should be installed on all roadways (Louisiana Department of Transportation and Development 2023).
Missouri	Edge line markings are provided on major roads, regionally significant roads, and minor roads (Missouri DOT 2017).
Montana	Edge line markings should be used wherever the paved roadway is at least 20 ft in width, regardless of ADT (Montana DOT 2009).
Nevada	6-in striping is required for rural roadways with an AADT higher than 400 vpd, for rural roadways with speeds exceeding 40 mph, and for list of specified state routes (Nevada DOT 2022).
New York	Edge line markings should be used on freeways and expressways and on all rural high-speed highways with posted speed limits of 45 mph and higher (New York State DOT 2018).
Pennsylvania	Table indicates when pavement markings should be provided on low volume roads based on ADT and district (Pennsylvania DOT 2016).
Virginia	Center line markings are required for all undivided limited access highways, bi-directional multi-lane roadways, and all other paved roadways (excluding residential streets) with a pavement width of at least 18 ft and ADT of at least 500 vpd (Virginia DOT 2013).
Washington	Edge line markings are required on all Interstate highways and rural multilane divided highways; and on all principal arterials and minor arterials located in urbanized areas, except on roadways with curb or sidewalk. Edge line markings are also required on paved rural arterials with a minimum traveled way width of 20 ft and ADT of at least 6,000 vpd. Edge line markings also may be utilized on other types of roads (Washington State Legislature 2023).
Wyoming	Center line markings are required on all undivided two-way highways on the state system with a width of at least 20 ft, regardless of ADT (Wyoming DOT 2012a).

Table 2-4. Center line marking warrants for Virginia DOT (adapted from Virginia DOT 2013).

Pavement Width	Traffic Volume	Undivided Limited Access	Bi-Directional Multi-Lane	Other Non-Local Residential	Other Local Residential	Short Segments not Meeting Requirements Between Segments Meeting Requirements
Greater than or equal to 18 feet	Greater than or equal to 500 vpd	Required	Required	Required	Optional	Recommended
Greater than or equal to 18 feet	Less than 500 vpd	Required	Required	Optional (if warranted)	Optional	Recommended
Less than 18 feet	Greater than or equal to 500 vpd	Required	Required	*	*	Recommended
Less than 18 feet	Less than 500 vpd	Required	Required	*	*	Recommended

* May be considered only where Engineering Judgement determines a need

3. DOT Interviews

This chapter provides an overview of the methodology and results for the DOT interviews.

Methodology for DOT Interviews

The research team conducted interviews with seven state DOTs regarding their practices for using wider pavement markings and pavement markings on low volume roads. A list of DOTs that were interviewed is provided in Table 3-1. This list was developed in consultation with the TAC. Criteria for selection included diversity with respect to geography, pavement marking width, and use of state-specific pavement marking warrants. Example interview questions are provided in Appendix B.

Table 3-1. State DOTs that were interviewed for this study.

State	Pavement Marking Width (Non-Freeways)	Has State-Specific Pavement Marking Warrant	Notes
Georgia	5 in	Yes	Uses 5-in markings
Iowa	4 in	No	Rural state
Michigan	In process of changing to 6 in	No	In process of changing to 6 in markings
Minnesota	6 in (edge lines), 4 to 6 in (other markings)	No	6 in for edge lines
New Hampshire	4 in	No	Similar to Missouri
Pennsylvania	4 in	Yes	Buys more paint than Missouri
Wisconsin	6 in (4 in allowed on local agency roads)	No	Some striping performed by counties

Results for DOT Interviews

Georgia DOT

Since the mid-1990s, the Georgia Department of Transportation (GDOT) has applied a uniform treatment of state routes with 5-inch wide markings to ensure consistency and visibility across all roads, regardless of traffic volume. GDOT uses thermoplastic and preformed plastic tape as the primary materials for striping, with regular beads added to improve retroreflectivity. The adoption of 5-inch markings was primarily driven by their safety and visibility benefits, including considerations for autonomous vehicles. The production and service life of 5-inch markings are comparable to those of 4-inch markings.

The main challenge during the transition to wider stripping was primarily communication across departments. For a seamless transition, fostering effective communication among all relevant departments, including maintenance, construction, traffic operations, research, and materials, is essential while considering all logistical and safety aspects. Establishing clear documentation and guidelines is also crucial for avoiding misunderstandings and ensuring uniformity across projects.

In terms of maintenance and management, GDOT performs many tasks in-house but also outsources striping work, particularly for larger corridors. The restriping frequency varies by road type, with major highways being restriped annually to once every four years. The frequency also depends on the condition of the pavement wear.

GDOT's plans include updating its road striping to wider, 6-inch markings. GDOT has faced challenges such as increased costs and material shortages, especially during the COVID-19 pandemic. Meanwhile, GDOT is constantly looking for innovative materials and technologies to make roads safer and the striping process more efficient.

Iowa DOT

The Iowa DOT categorizes roadways into three tiers: DOT-maintained roads, county roads, and municipal roads. The Iowa DOT oversees approximately 9,600 miles of DOT-maintained roadways, including ramps. Local agencies oversee and maintain county and municipal roadways. Currently, the state employs 4-in wide pavement markings, with a policy to restripe centerlines and lane lines annually and edge lines biennially. Recently, initiatives to incorporate grooved lines have started. The use of multi-component pavement markings is also increasing on high-volume roads (primarily Interstates), reducing the need for annual restriping and increasing the safety for crews since they are not out on the highest speed/highest volume roadways. Shoulder rumble strips are a primary safety feature, with center line rumble strips currently being added to the system.

Iowa DOT plans to transition to 6-in wide pavement markings across the state in 2025 and 2026. The upgrade from 4-in to 6-in markings aims to enhance visibility and safety for drivers. In an informal pilot, the state upgraded pavement markings to 6-in widths in six safety corridors, incorporating additional safety measures. This move towards wider markings, supported by collaboration with the Iowa State University Institute for Transportation, follows practices already adopted by neighboring states like Minnesota and Illinois. The shift to 6-in markings was initially constrained by budget limitations, and a recent doubling of the maintenance budget for materials has facilitated the move towards wider lines.

Maintenance of pavement markings is primarily conducted in-house by the Iowa DOT, with contractors handling initial markings on construction projects. For interstates requiring multi-component epoxy markings (new and restripe/maintenance), contractor services are used. To maintain productivity and quality, field crews work extended hours (e.g., a four-day, 10-hour schedule per week), employing advanced equipment such as paint trucks capable of painting two lines simultaneously and nurse trucks to supply materials throughout the workday.

Policy changes are expected to adopt a more data-driven, quality-focused approach, evaluating pavement marking performance based on reflectivity. This approach aims to refine annual painting programs, potentially reducing the frequency of restriping as advancements in pavement marking materials and technology are implemented.

Michigan DOT

MDOT maintains approximately 10,000 miles of state trunkline. Each year, MDOT stripes approximately 28,400 marking miles, which accounts for 85 to 90 percent of their roadways. The remaining 10 to 15 percent of roadways, which do not get restriped in a given year, are either under construction or have durable pavement markings. MDOT contracts out all of their striping work.

MDOT has been using 6-in edge lines on all trunkline roadways since approximately 2004. In 2020, they began using 6-in lane lines on freeways. In 2021, they upgraded lane lines to 6 in markings on non-freeways. From 2022 to 2024, they implemented a three-year conversion from 4 to 6 in markings on center lines and lane lines. Wider pavement markings have been implemented on all roadways maintained by MDOT regardless of roadway characteristics (e.g., AADT, functional class, potential for run-off-road crashes). Thus, by the end of 2024, all edge lines, center lines, and lane lines on state-maintained roadways will be 6 in.

A challenge MDOT faced in switching to wider pavement markings was switching from a three-gun paint gun system to a two-gun paint gun system, as illustrated in Figure 3-1.

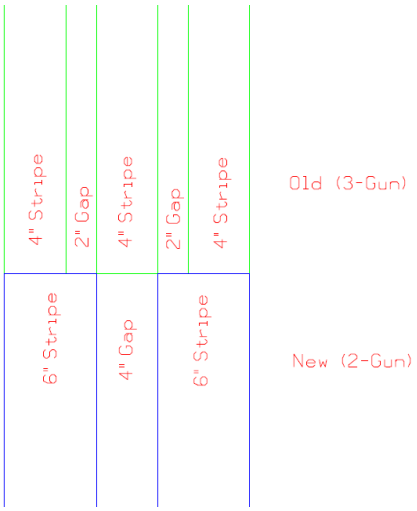

Figure 3-1. Conversion from a three-gun paint gun to a two-gun paint gun (Courtesy of MDOT).

This conversion resulted in removal of a substantial amount of center line striping. Specifically, anywhere that a solid and skip combination line was in place, the 4-in center stripe (see center stripe in top half of Figure 3-1) needed to be removed to accommodate the 4-in gap between the two 6-in stripes (see bottom half of Figure 3-1).

The use of wider pavement markings has not slowed down production for MDOT because their contractor was able to increase their capacity/availability, and MDOT was able to manage the increased cost. Thus, striping productivity has not been impacted.

While MDOT has not conducted any studies evaluating the performance of wider pavement markings, they have observed that the wider markings better survive snowplow activity. In other words, more paint remains after a winter season of snowplowing. MDOT has not, however, evaluated the service life of the retroreflectivity of the markings.

Striping practices do not vary between rural and urban areas. The only difference is that striping is often performed at night in urban areas to avoid heavy traffic.

The primary materials used by MDOT are water-borne paint and sprayable thermoplastic, which are used in the annual restriping program, covering 85 to 90 percent of the state-maintained roadways.

MDOT uses some long-life polyurea and modified epoxy, but the application of these materials is limited to construction projects.

Regarding the use of wider striping, MDOT believes that 6-in edge lines are better than 4-in edge lines for both visibility and durability, and they have been happy with the performance of 6-in edge lines. Regarding striping on low-volume roads (less than 400 AADT), MDOT believes that every little bit helps and that a stripe is better than a dark road, even if the stripe is only 4 in wide.

Other strategies used by MDOT to try and reduce run-off-road crashes include shoulder and center line rumble strips and post-mounted delineators. MDOT was one of the first state DOTs to implement center line rumble strips statewide in 2008. This resulted in a 51-percent reduction in fatalities statewide wherever centerline rumble strips were installed. Shoulder rumble strips are implemented when the shoulder is wide enough. Sinusoidal rumble strips are used for non-freeway shoulders. Post-mounted delineators are used to delineate curves on non-freeways. For freeways and divided highways, delineators are placed at least every 400 ft so they can be seen in poor weather conditions. Delineators are also used on guardrail and other barriers.

MDOT is not currently planning any changes to its pavement marking policies in the near future. However, if they could afford it, they would like to expand the requirement of wet reflective lane lines to non-freeways (currently wet reflective lane lines are required on freeways).They are also investigating the possibility of restriping every other year, rather than every year, on some low-volume roadways, to help address increased material costs and budget overruns.

Minnesota DOT

MnDOT maintains approximately 12,000 miles of roads on its highway system, which represents approximately 10 percent of the roads in Minnesota. MnDOT performs a majority of its restriping in-house.

MnDOT switched from 4-in to 6-in markings for edge lines in 2022. However, 4-in lines are used for center line markings in most MnDOT districts. Two of MnDOT's districts also use 6-in markings for center line markings. MnDOT's policy for pavement markings is described in its Traffic Engineering Manual (Minnesota DOT 2023b). MnDOT based the decision to change to 6-in markings based on the Crash Modification Factors (CMFs) in the CMF Clearinghouse and the changes that were anticipated in the new version of the MUTCD. Considerations for connected and automated vehicles helped to initiate the conversation regarding wider pavement markings. In addition to wider pavement markings, MnDOT also uses rumble strips in an effort to reduce run off the road crashes.

There were some initial challenges to getting agency buy-in for the change. In addition, the change to wider striping resulted in a speed reduction for striping vehicles from 10 mph to 8 mph or 7 mph. However, MnDOT had enough capacity remaining in its striping trucks to perform the needed striping. MnDOT also tried different head tips to accommodate the wider striping. MnDOT estimated an annual cost increase of $3 million (2019 average bid cost numbers) for using the wider striping but believes that the safety benefits outweigh the increased cost.

For marking materials, MnDOT typically utilizes ground-in epoxy or ground-in high build latex. The epoxy markings typically last seven years, while the latex markings typically last three or four years. In addition, some tape is used for broken line markings. MnDOT does not have many low volume roads on the state

system but stripes them. MnDOT has also implemented minimum wet retroreflectivity values for new markings.

In the future, MnDOT may make some changes to the minimum wet retroreflectivity values. In addition, MnDOT may switch from the oreo pattern to the lead-lag pattern for contrast pavement markings.

New Hampshire DOT

NHDOT maintains approximately 4,000 miles of roadway markings on its highway system. NHDOT categorizes their roadways as follows:

- Tier 1 – Interstates
- Tier 2 – Major US routes and NHS routes
- Tier 3 – Other numbered routes
- Tier 4 – Unnumbered secondary routes

While all roadways are planned for restriping annually, they are prioritized from Tier 1 (highest priority) to Tier 4. If there are limitations in calendar time (due to seasonal changes or weather) or striping capacity (personnel), the edge lines of some Tier 4 roadways may not get restriped until the following year (center line markings typically get restriped every year). When this occurs, NHDOT tries not to skip the same roadway two years in a row.

Current NHDOT policy is to use 6-in edge lines and lane lines on interstates and 4-in center lines and edge lines on all other roads. Some higher-speed Tier 2 roadways have 4-in center lines and 6-in edge lines. Per MUTCD guidance, NHDOT stripes all roadways with a minimum width of 20 ft. If a roadway is less than 20 ft in width, no center line or edge line markings are provided.

Striping practices do not vary between rural and urban areas. If a state route goes through an urban compact, the city is responsible for the striping but should follow NHDOT standard plans and specifications (New Hampshire DOT 2016, New Hampshire DOT 2024).

The primary material used by NHDOT is waterborne paint for maintenance of edge lines, center lines, and stencil markings. NHDOT utilizes polyurea as an inlay on new pavement after a 90-day wait period. Polyurea is primarily used on interstates for all the long-line markings (median lines, lane lines, and edge lines). Thermoplastic is used for lane lines on new asphalt. The durable marking program was reinitiated approximately four years ago. Since durable markings last between four and five years, these markings have not yet had to be replaced.

NHDOT contracts some of their resurfacing projects, and on these projects, the striping is performed by the contractor. Following this initial striping by a contractor, NHDOT takes over the striping maintenance. The only exception is the maintenance of any durable markings, which is contracted out.

For the past nine years, NHDOT has had data logging equipment on its maintenance trucks. This equipment provides the striping crew with accurate information about the thickness of material being applied. In other words, the crew receives real-time feedback on whether too much, too little, or just the right amount of material is being applied.

Other strategies used by NHDOT to try and reduce run-off-road crashes include a rumble strip program and a comprehensive horizontal curve warning sign program. The rumble strip program targets center lines or shoulders (or both) on Tier 1 and Tier 2 roadways. If a safety issue is identified on a Tier 3 or Tier 4 roadway, rumble strips may be considered to address the issue. Some resistance to rumble strips from residents in abutting properties has resulted in NHDOT focusing on sinusoidal rumble strips. The horizontal curve warning sign program has been in place for the past four or five years. Every horizontal curve has been assessed to make sure signing is consistent with the MUTCD. Fluorescent yellow signs and chevrons, where appropriate, have been implemented. Every curve is treated consistently.

NHDOT is not currently considering the use of wider pavement markings in the future. Because of the added cost of wider pavement markings, changing to wider markings would result in Tier 4 roads getting striped less frequently.

NHDOT is considering implementing additional durable pavement markings on Tier 1 roadways to increase visibility. A challenge they may be facing in the future, though, is staffing. Thus, more pavement marking maintenance may need to be performed by contractors.

Pennsylvania DOT

The Pennsylvania Department of Transportation (PennDOT) maintains nearly 40,000 miles of roadway. Each year, PennDOT maintenance crews stripe 90,000 pavement marking miles, and an additional 5,000 pavement marking miles are striped by a contractor. The 95,000 pavement marking miles are restriped with waterborne paint. Roads with waterborne paint are striped yearly. If a durable marking was placed as part of a construction project, then it is restriped after three years, usually with waterborne paint.

PennDOT installs longitudinal pavement markings on roadways on the state highway system as follows (Pennsylvania DOT 2017):

- First and Second Class Cities
    - All interstate and limited access highways.
- Third Class Cities and Boroughs
    - All interstate and limited access highways.
    - All numbered traffic routes that are curbed or uncurbed, where parking is permitted, with a minimum pavement width of two, 10-ft traffic lanes plus an 8-ft parking area.
    - All numbered traffic routes with pavement widths greater than or equal to 16 ft that are structurally adequate and can safely accommodate paint machines.
    - Other selected highways.
- Townships
    - All interstate and limited access highways.
    - All three, four, five, six, and eight-lane divided and undivided highways.
    - Numbered traffic routes with pavement widths greater than or equal to 16 ft that are structurally adequate and can safely accommodate paint machines.

- Two-lane highways having ADT greater than or equal to 500 vpd and pavement width greater than or equal to 16 ft that are structurally adequate and can safely accommodate paint machines.
- Roads that are not numbered traffic routes having ADT less than 500 vpd and pavement widths greater than or equal to 16 ft that are structurally adequate and can safely accommodate paint machines will be determined by each district.
- Other selected highways.

The primary material used by PennDOT is waterborne paint, and, in fact, PennDOT striping crews only use waterborne paint. Construction projects (resurfacing or new pavement) generally require durable pavement markings, such as epoxy, thermoplastic, polyurea, methyl methacrylate (MMA), or all-weather striping tape.

Current PennDOT standards are to use 4-in edge lines with 6-in edge lines being optional on limited access roadways. Table 3-2 presents PennDOT policy regarding pavement markings on low-volume roads, which varies by district. Some districts believe that 16-ft roadways may be too narrow to stripe and are considering increasing the minimum pavement width for striping to 18 ft.

Table 3-2. PennDOT policy regarding pavement markings on low-volume roads (Pennsylvania DOT 2016).

District	<200 ADT	<500 ADT	500-1,000 ADT	>1,000 ADT	All Roads
1-0	No paint	No paint	No paint	Center and edge lines	-
2-0	No paint	No paint	-	-	-
3-0	No paint*	-	-	-	-
4-0	-	-	-	-	X
5-0	-	-	-	-	X
6-0	-	-	-	-	X
8-0	-	-	-	-	X
9-0	No paint	No paint	-	-	-
10-0	No paint	No paint	-	-	-
11-0	No paint	No paint**	-	-	-
12-0	No paint	No paint	No paint	-	-

*No paint on roads with <200 ADT and <18’ width

**Roads with <500 ADT and/or 20’ width painted every other year

Striping practices do not vary between rural and urban areas. However, production is lower in urban areas due to higher traffic volumes. Minimal striping is performed during nighttime hours (only one or two districts).

Over the years, PennDOT has been focused on maximizing striping production but has experienced a negative impact on quality. PennDOT is trying to work with striping crews to improve quality while not hindering production. Notably, however, if PennDOT receives complaints from the public about pavement markings, they are typically about the lack of striping rather than the quality of striping.

Other strategies used by PennDOT to try and reduce run-off-road crashes include raised pavement markers (RPMs), recessed all-weather pavement markings, and delineation. PennDOT has experienced some challenges with RPMs coming loose during snowplow activities. Delineation includes post-mounted delineators, guide rail delineation, and delineation on barriers.

Maintenance funding is already limited, so if PennDOT were to change to wider markings, the additional cost for wider lines would result in the removal of some roadways from the striping program. PennDOT would like to expand the use of recessed all-weather pavement markings to non-interstates and gradually phase out RPMs.

Wisconsin DOT

The Wisconsin Department of Transportation (WisDOT) maintains approximately 40,000 marking miles on its highway system. WisDOT contracts striping for US highways, Interstates, and some state highways. In addition, WisDOT has a Traffic Management Agreement with 25 counties for the counties to perform the striping on state highways.

WisDOT switched from 4-in to 6-in markings for US highways, Interstates, and state highways in November 2023. However, the use of 4-in markings is still allowed on local agency roads. A memorandum was issued on March 1, 2023 describing the policy change (Wisconsin DOT 2023). WisDOT based the decision to change to 6-in markings based on the Crash Modification Factors (CMFs) in the CMF Clearinghouse and the changes that were anticipated in the new version of the MUTCD. There were some initial concerns from counties regarding the change to 6-in markings (e.g., perceived short length of time to implement the change), but these concerns were resolved. In addition, some paint crews needed to purchase additional equipment to accommodate the wider striping. WisDOT has encountered some challenges with funding for the wider striping and has seen prices increase by approximately 20 percent, which is less than the anticipated price increase. WisDOT tries to group projects into longer segments to increase striping efficiency. In addition to 6-in markings, WisDOT has also implemented wet reflective edge lines and edge line rumble strips as countermeasures for run off the road crashes.

For marking materials, WisDOT typically utilizes standard epoxy (AADT less than 1,500 vpd) and wet reflective markings (center lines, AADT more than 1, 500 vpd). Waterborne paint is used by the counties and for low volume roads. WisDOT does not have many low volume roads on the state system but stripes most of them annually. Durable markings are typically applied every three to five years. In addition, WisDOT utilizes tape contrast markings for lane lines. WisDOT began using the lag pattern (instead of the oreo pattern) for contrast markings for lane lanes in late 2023. Also, in late 2023, WisDOT started requiring center line markings to be grooved in. Previously, center line markings were not grooved in.

In the future, WisDOT would like to develop state specific CMFs for striping width. In addition, WisDOT is considering changes to bead packages and practices for temporary pavement markings.

Summary of DOT Interviews

A summary of key findings from the interviews with seven DOTs is provided below.

- Six of these DOTs use wider pavement markings (greater than 4 in.) to some extent. The extent of implementation of wider striping varies based on the type of line (e.g., edge line only or all lines) and type of roadway (e.g., interstate or other roadways). In some cases, the extent of implementation of wider striping varies between DOT districts.
- Three of these seven DOTs have either switched to 6-in markings or have expanded their use of 6-in markings since 2020. Two DOTs are planning to switch to 6-in markings in the future.
- DOTs that have switched to wider pavement markings have typically based the decision on the CMFs in the CMF Clearinghouse (FHWA 2024), anticipated changes to the MUTCD (FHWA 2023), and, in some cases, considerations for connected and automated vehicles.
- Challenges that these DOTS have faced in changing to wider markings include communication across departments, getting agency buy-in, budget considerations, striping capacity, and changes in striping equipment or the need to purchase additional striping equipment. Some DOTs have been able to manage the increased cost of wider striping through additional funding or other means. In addition, some DOTs have had additional capacity to accommodate wider striping. However, NHDOT and PennDOT would have to reduce striping on low volume roads to accommodate an expansion of wider striping.
- These DOTs utilize various strategies to help maximize production while maintaining quality, such as grouping projects into longer segments, working with striping crews to improve quality, working extended hours, employing advanced equipment, and exploring new technologies and materials.
- Materials used for striping include waterborne paint, epoxy, ground-in high build latex, polyurea, thermoplastic, and tape.
- In general, DOTs participating in the interviews that use wider markings have not observed any difference in service life. However, MDOT has observed that wider markings are more resistant to snowplow activity.
- DOTs often perform striping maintenance in-house but also outsource some striping work to contractors and counties.
- Striping practices typically do not vary between rural and urban areas, although in some cases municipalities are responsible for striping in urban areas. Striping work in urban areas is sometimes performed at night when traffic volumes are lower. Higher traffic volumes can lead to reduced striping production in urban areas.
- Practices for applying striping on low volume roads include striping all roads (especially if the quantity of low volume roads under DOT jurisdiction is minimal), striping roads above minimum thresholds for width and/or AADT, and prioritizing roads for striping based on categories. In some cases, higher volume roads are striped more frequently. Practices for applying striping on low volume roads sometimes vary between districts of a given DOT.
- Examples of other safety countermeasures used by these seven DOTs to reduce run off the road crashes include rumble strips, horizontal curve warning signs, post-mounted delineators, RPMs, and recessed all-weather pavement markings.
- Examples of ways these DOTs are considering making possible future changes to their practices for pavement marking include implementation of additional durable pavement markings to

increase visibility, development of state specific CMFs for striping width, incorporation of more data-driven approaches, exploration of new materials and technologies to enhance efficiency of roadway striping, expansion of the use of recessed all-weather pavement markings, and modifications to bead packages, practices for temporary pavement markings, minimum wet retroreflectivity values, and patterns for contrast pavement markings.

4. Conclusions

This chapter presents the overall conclusions of the research, organized by topic.

Pavement Marking Width

- The 2023 edition of the MUTCD requires normal edge lines to be 4 to 6 in wide (FHWA 2023). However, the 2023 edition also includes supplemental language indicating that using wider edge lines at 6 in is optional but can offer greater emphasis and has shown improved safety at locations with a history of run-off-road crashes.
- MoDOT's current practices for pavement marking width include both 4-in and 6-in markings. As noted in the MoDOT EPG (MoDOT 2017), white edge lines and center lines and yellow edge lines on all major routes should be 6 in wide, and all other markings should be 4 in wide. Marking materials should consist of high build waterborne paint with Type L beads for major routes and waterborne paint with Type P beads for other routes.
- A review of previous research studies on the safety performance of wider pavement markings indicates that, while some of the older studies showed inconsistent and inconclusive research findings, more recent research (2011 to 2023) has shown safety benefits associated with the use of wider pavement markings. Research studies have shown crash reductions for wider pavement markings ranging from 7 percent to 30 percent (total crashes) and from 14 percent to 51 percent (fatal and injury crashes) and benefit-cost ratios ranging from 24:1 to 55:1.
- Results from human factors studies have shown mixed results regarding the effects of marking width on lane position and encroachment (Miles et al. 2010, Abdel-Rahim et al. 2018).
- Limited research has indicated that wider pavement markings (6 in) outperformed 4-in markings with respect to machine vision detection, especially at longer distances (Davies 2017).
- The literature review did not identify any research regarding considerations for pavement marking width based on striping capacity constraints.
- A review of DOT guidance and standards indicates that most state DOTs use 6-in markings (or, in some cases, 5-in markings) to some extent. Fourteen state DOTs utilize 4-in markings on freeways, while 11 state DOTs follow the national MUTCD guidance of 4-in to 6-in markings. Other state DOTs use 6-in markings for certain types of roadways (e.g., interstates, freeways).
- For non-freeways, 18 state DOTs utilize 4-in markings on non-freeways, while 11 state DOTs follow the national MUTCD guidance of 4-in to 6-in markings. Other state DOTs use 6-in markings for certain types of roadways (e.g., National Highway System) or roadways meeting minimum thresholds for Annual Average Daily Traffic (AADT) and/or speed.
- Six of the seven DOTs that participated in the interviews use wider pavement markings (greater than 4 in.) to some extent. The extent of implementation of wider striping varies based on the type of line (e.g., edge line only or all lines) and type of roadway (e.g., interstate or other roadways). In some cases, the extent of implementation of wider striping varies between DOT districts.
- With respect to the timing of implementation, three of these seven DOTs have either switched to 6-in markings or have expanded their use of 6-in markings since 2020. Two DOTs are planning to switch to 6-in markings in the future.

- DOTs that have switched to wider pavement markings have typically based the decision on the CMFs in the CMF Clearinghouse (FHWA 2024), anticipated changes to the MUTCD (FHWA 2023), and, in some cases, considerations for connected and automated vehicles.
- While the DOT interviewees that use wider markings have not observed any difference in service life, one DOT has observed that wider markings are more resistant to snowplow activity.

Use of Pavement Markings on Low Volume Roads

The MUTCD includes requirements for center line markings for different facility types based on minimum thresholds for average daily traffic (ADT) and traveled way width (FHWA 2023).

- MoDOT's pavement marking guidelines state that major roads and regionally significant roads should be striped annually (MoDOT 2017). In addition, minor roads with AADTs of at least 400 vpd should be striped every other year, and minor roads with AADTs less than 400 vpd should be striped every three years.
- A review of state DOT guidance and standards for use of pavement markings on low-volume roads found that 11 other state DOTs, besides MoDOT, have state-specific warrants for center line or edge line markings. These state-specific warrants go beyond the MUTCD warrants by lowering the ADT or width thresholds and are sometimes based on facility type.
- As noted in the DOT interviews, practices for applying striping on low volume roads include striping all roads (especially if the quantity of low volume roads under DOT jurisdiction is minimal), striping roads above minimum thresholds for width and/or AADT, and prioritizing roads for striping based on categories. In some cases, higher volume roads are striped more frequently. Practices for applying striping on low volume roads sometimes vary between districts of a given DOT.

Implementation Considerations

- Challenges that the DOTs participating in the interviews have faced in changing to wider markings include communication across departments, getting agency buy-in, budget considerations, striping capacity, and changes in striping equipment or the need to purchase additional striping equipment.
- Some DOTs have been able to manage the increased cost of wider striping through additional funding or other means.
- In addition, some DOTs have had additional capacity to accommodate wider striping. However, two DOTs that participated in the interviews indicated that they would have to reduce striping on low volume roads to accommodate an expansion of wider striping.
- The DOTs that participated in the interviews utilize various strategies to help maximize production while maintaining quality, such as grouping projects into longer segments, working with striping crews to improve quality, working extended hours, employing advanced equipment, and exploring new technologies and materials.

Summary of Findings

Overall, the existing research provides more support for the use of wider pavement markings than for the use of pavement markings on low volume roads. Given these findings, MoDOT could explore the use of 6-in markings on minor routes and the elimination of pavement markings on some low volume roads.

MoDOT could also consider a hybrid approach, such as the use of 5-in edge lines on other routes and the development of warrants for center line markings on low volume roads based on AADT, width, and/or speed. Based on the experiences of other DOTs, important considerations for the use of wider pavement markings include striping capacity, budget constraints, and equipment needs. MoDOT could also explore strategies to help maximize striping production, such as grouping projects into longer segments, employing advanced equipment, and new technologies and materials.

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Appendix A: Summary of Existing Literature and DOT Resources for Pavement Marking Width and Use of Pavement Markings on Low Volume Roads

Table A-1. Summary of general literature regarding pavement marking width.

Title	Reference	URL	Summary
Safety Impacts of Using Wider Pavement Marking on Two-Lane Rural Highways in Idaho	Abdel-Rahim et al. 2018	https://rosap.ntl.bts.gov/view/dot/63580	This study included a driving simulator study and analysis of crash data (using before-after with comparison group and Empirical Bayes methods) for two-lane highways in Idaho. Findings from the driving simulator study found that pavement marking width by itself did not influence lane position. Results from the Empirical Bayes method indicated that wider pavement markings reduced the number of crashes by 17 percent and fatal and severe injury crashes by 14 percent. Crash rates were reduced by 5.53 percent (total crashes) and 12.59 percent (severe injury crashes). The benefit-cost ratio of wide pavement markings on Idaho two-lane highways was found to be approximately 1:25. Results also indicated that 6-in markings degrade at a slower rate than 4-in markings.
Making Our Roads Safer One Countermeasure at a Time	Albee and Bobitz 2021	https://safety.fhwa.dot.gov/provencountermeasures/pdf/FHWA-SA-21-071_PSC%20Booklet_508.pdf	Wider edge lines are considered as one of FHWA's proven safety countermeasures.
An Evaluation of the Effectiveness of Wider Edge Line Pavement Markings	Carlson and Wagner 2012	https://static.tti.tamu.edu/tti.tamu.edu/documents/TTI-2012-1.pdf	Based on a literature review, wider edge lines have been associated with crash reductions of 15 percent to 30 percent (total crashes) and 15 percent to 38 percent (fatal plus injury crashes). Results from an economic analysis of data from Kansas (Park et al. 2012) indicated benefit-cost ratios of 33:1 to 55:1.

Title	Reference	URL	Summary
Evaluation of Wide Edge Lines on Two-Lane Rural Roads	Cottrell 1987	https://rosap.ntl.bts.gov/view/dot/20443	This study investigated the impacts of 8-in wide edge lines on run-off-road and other related crashes on two-lane highways in Virginia using two statistical methods: before-after with comparison group and Gart's procedure. Results indicated that the use of 8-in-wide edge lines resulted in no statistically significant reductions in run-off-road crashes.
Effects of Pavement Marking Characteristics on Machine Vision Technology	Davies 2017	https://trid.trb.org/view/1438482	Based on static testing of a stationary vehicle in a parking lot, wider pavement markings (6 in) outperformed 4-in markings with respect to machine vision detection, especially at longer distances. Findings also indicated that the wider markings may help to counter lower retroreflectivity and may lengthen the service life of the pavement markings.
Manual on Uniform Traffic Control Device 10th Edition (MUTCD)	FHWA 2009	https://mutcd.fhwa.dot.gov/pdfs/2009/pdf_index.htm	Normal edge lines shall be 4 to 6 in wide. Wide solid edge line markings may be used for greater emphasis.
Manual on Uniform Traffic Control Device 11th Edition (MUTCD)	FHWA 2023	https://mutcd.fhwa.dot.gov/pdfs/11th_Edition/mutcd11thedition.pdf	The widths of edge lines shall be 4 to 6 in wide. Using wider edge lines at 6 in is optional but can offer greater emphasis and has shown improved safety at locations with a history of run-off-road crashes. To accommodate automated vehicles, agencies should consider edge lines of at least 6 in wide.

Title	Reference	URL	Summary
The Use of Wider Longitudinal Pavement Markings	Gates and Hawkins 2002	https://static.tti.tamu.edu/tti.tamu.edu/documents/0024-1.pdf	The study methodology included agency surveys and a review of technical literature. The survey identified 29 state DOTs that use wider pavement markings to some extent. The researchers found a lack of conclusive data on crash reduction or extended service life associated with the use of wider markings. The researchers found that some agencies use indirect safety measures (e.g., driver opinion surveys and surrogate measures) to assess the performance of wider pavement markings. Agencies generally indicated that they were satisfied with the use of the wider markings. Researchers found that wider markings may offer significant benefits when applied in horizontal curves, narrow shoulders, work zones, areas with low luminance contrast, and where older drivers are predominant.
Evaluation of Wide Edgelines	Hall 1987	https://onlinepubs.trb.org/Onlinepubs/trr/1987/1114/1114-002.pdf	This study assessed the safety effects of using 8-in wide edge lines on rural two-lane highways in New Mexico based on the before-after with comparison group method. Findings indicated that the 8-in-wide edge lines resulted in no statistically significant difference in run-off-road crashes, including run-off-road crashes at night or on horizontal curves and crashes involving the opposing traffic lane.
Field Evaluation of Edgeline Widths	Hughes et al. 1989	https://babel.hathitrust.org/cgi/pt?id=ien.35556021515754&seq=1	This research study investigated the safety effects of 8-in wide edge lines on rural two-lane highways using data from seven states and the before-after with comparison group method. Findings indicated that, compared with 4-in-wide edge lines, 8-in-wide edge lines did not reduce crash frequency on roads with AADT ranging from 5,000 to 10,000 vpd. The authors concluded that the 8-in wide edge line markings could be cost effective for the following conditions: average daily traffic volumes between 2,000 and 5,000 vpd, high frequency of rainfall, and pavement widths of 24 ft and unpaved shoulders.

Title	Reference	URL	Summary
Investigating Safety Effects of Wider Longitudinal Pavement Markings	Hussein et al. 2020*	https://doi.org/10.1016/j.aap.2020.105527	Utilizing data from 38 highway sites across British Columbia, Alberta, and Quebec over eight years, the study employed a Full Bayes analytical approach. The findings indicated a significant reduction in collisions after implementation of wider markings, with total collisions decreasing by 12.3 percent and run-off-road collisions decreasing by 19.0 percent.
Evaluation of Potential Benefits of Wider and Brighter Edge Line Pavement Markings	Miles et al. 2010	https://rosap.ntl.bts.gov/view/dot/18315	This research study examined the use of wider pavement markings on two-lane highways through a literature review, state survey, analysis of crash data from Michigan and Illinois, and human factors study. Results from the safety analysis indicated crash reductions from the use of wider pavement markings, with crash reductions of 7.1 percent (all crashes) and 17.1 percent (fatal injury crashes) reported from an Empirical Bayes before-after analysis of the Michigan data. Results from the human factors study showed that encroachment on the edge line on the inside of horizontal curves decreased as the edge line marking width increased. In addition, study participants stayed farther from the edge line on tangent sections with higher edge line marking widths.
Use of Wider Pavement Markings – Survey of State Transportation Agencies	Obeng-Boampong et al. 2009	-	In this study, a survey of state DOTs on the use of wider pavement markings was conducted. Results indicated that wider pavement markings are increasingly being used by states, with 76 percent of responding state DOTs implementing wider markings. The authors concluded that the increased usage of wider pavement markings seems to be driven more by subjective assessments and state policies. The primary implementation challenges were identified as cost and a lack of research on the safety benefits of wider pavement markings. States indicated that wider pavement markings are generally well-received by the public. The authors identified a need for more objective research to conclusively determine the safety benefits of wider pavement markings.

Title	Reference	URL	Summary
Safety Effects of Wider Edge Lines on Rural, Two-Lane Highways	Park et al. 2012*	https://www.sciencedirect.com/science/article/pii/S0001457512000486	Crash frequency data for three states (Kansas, Michigan, and Illinois) were analyzed using Empirical Bayes before-after and cross-sectional methods to assess the safety effects of wider edge lines. Results indicated crash reductions of 17.5 percent to 30.1 percent (total crashes) and 15.4 percent to 37.7 percent (fatal plus injury crashes).
Benefit/Cost Evaluation of MoDOT's Total Striping and Delineation Program: Phase II	Potts et al. 2011	https://rosap.ntl.bts.gov/view/dot/23053	The study included an evaluation of the safety effects of wider pavement markings using Missouri data from the Smooth Roads Initiative with the Empirical Bayes before-after method. The use of wider marking without resurfacing was associated with a 22.4 percent reduction in fatal and injury crashes on rural freeways and a 50.8 percent crash reduction in fatal and injury crashes on urban freeways. The benefit-cost ratio of wider markings without resurfacing was calculated as 23.8 for rural freeways and 28.5 for urban freeways.

* Indicates CMFs from study are included in CMF Clearinghouse (FHWA 2024)

Table A-2. Summary of general literature regarding pavement markings on low volume roads.

Title	Reference	URL	Summary
Need for Center Markings on Low-Volume Rural Roads	Glennon 1984	http://onlinepubs.trb.org/onlinepubs/nchrp/NCHRP_20-7_21_1984/NCHRP_20-7_21_1984.pdf	The study methodology consisted of a survey and analysis of traffic and crash data for low volume (less than 400 vpd) two-lane rural roads under the federal Pavement Marking Demonstration program. Results showed that the use of center line markings did not appear to reduce crash rates. Warrants for center line markings were developed based on road width and ADT (e.g., 500 vpd for roadway width greater than 20 ft).
Evaluation of Pavement Markings on Low-Volume Rural Roadways in Iowa	Knapp et al. 2015	https://publications.iowa.gov/27236/1/final%20report%20-%20eval_of_low-volume_rural_pvmt_markings_w_cvr.pdf	The objective of this study was to assess the state of the practice for the use of pavement markings on low volume roads in Iowa through a literature review, survey of Iowa county engineers, and benefit-cost analysis. Survey results indicated that 97 percent of respondents used painted center lines and edge lines to some extent on low volume roads. Results from the benefit-cost analysis showed that a crash reduction of 5.1 percent would make the use of pavement markings on low volume roads beneficial.
Safety Aspects of Line Markings on Two-Lane Low-Volume Narrow Roads in Virginia	Kweon et al. 2015	https://www.davidpublisher.com/Public/uploads/Contribute/56404aa47d918.pdf	This study included the evaluation of five years of crash data on low volume (3,000 vpd or less) narrow (20 ft or less) roads in Virginia. The following four marking configurations were studied: no markings, center line markings only, edge line markings only, and both center line and edge line markings. Results indicated that there was no statistical difference in safety performance between low volume narrow roads with or without center lines or edge lines.
Guidelines for Application of Selected Signs and Markings on Low-Volume Rural Roads	Stockton et al. 1976	https://onlinepubs.trb.org/Onlinepubs/trr/1976/597/597-004.pdf	Probability of conflict analyses were applied to assess the need for pavement markings on segments with inadequate passing sight distance on low volume (ADT less than 400 vpd) rural roads. The results showed no benefit to the use of striping at these locations due to the low probability of a conflict. As an alternative, the use of a PASSING HAZARDOUS sign or double narrow lane marking (1.5-in lines with 1-in space) was suggested.

Title	Reference	URL	Summary
Safety Improvement from Edge Lines on Rural Two-Lane Highways	Sun and Das 2012*	https://rosap.ntl.bts.gov/view/dot/24250	This study included a before-after safety analysis to assess the safety impacts of edge lines on narrow (less than 22 ft) rural two-lane highways in Louisiana. Three years of before crash data and one year of after crash data were used. Results showed a reduction in expected crashes of 17 percent with the use of edge lines. The researchers suggested the prioritization of roadways with higher volumes if financial or operational constraints exist.
A Comprehensive Study on Pavement Edge Line Implementation	Sun and Das 2014*	https://rosap.ntl.bts.gov/view/dot/27322	This study utilized the Empirical Bayes method to assess the safety impacts of edge lines on narrow (pavement width greater than or equal to 20 ft and less than 22 ft) rural two-lane highways in Louisiana. Three years of before crash data and three years of after crash data were used. Results showed a reduction in expected crashes of 15 percent with the use of edge lines. A benefit-cost ratio of 19:1 was estimated. The researchers suggested the prioritization of roadways with higher volumes if financial or operational constraints exist.
Impact of Edge Lines on Safety of Rural Two-Lane Highways	Sun and Tekell 2005	https://rosap.ntl.bts.gov/view/dot/22132	This research study included a field evaluation for the use of edge lines on Louisiana roads with a narrow width (20 ft to 22 ft). Results showed that edge lines helped drivers stay in their travel path but did not affect drivers' speeds. While calculating crash reductions was outside the scope of the study, researchers indicated that the magnitude of the safety impact of wider edge lines on rural two-lane highways varies based on factors such as roadway width, operating speed, time of day, percent of heavy vehicles, pavement condition, roadway alignment, and opposite direction traffic.

Title	Reference	URL	Summary
Investigating the Necessity and Prioritizing Pavement Markings on Low-Volume Roads	Veneziano and Smadi 2018	https://rosap.ntl.bts.gov/view/dot/36405	The researchers provided an overview of pavement marking practices in Minnesota and highlighted the need for a systematic approach to prioritize pavement markings on local roadways, especially considering budget constraints and safety benefits. They developed a spreadsheet tool to facilitate the evaluation and prioritization of various pavement marking alternatives, including center lines only, edge lines only, both center lines and edge lines, high-visibility markings, and enhanced durability markings. The developed tool was based on current practices and policies, with a goal of aiding in decision-making for pavement marking installations.

* Indicates CMFs from study are included in CMF Clearinghouse (FHWA 2024)

Table A-3. Summary of DOT guidance and standards regarding pavement marking width and pavement markings on low volume roads.

State	Title	Reference	URL	Summary
Alabama	Standard Specifications for Highway Construction (Section 701: Traffic Stripe)	Alabama DOT 2022	https://www.dot.state.al.us/publications/Construction/pdf/Specifications/2022/SpecBookComplete.pdf	According to Section 701.03 (Construction Requirements), Class I Paint for permanent markings and Class IH, High Build Paint are placed as a 5-in wide stripe.
Alabama	Standard and Special Drawings for Highway Construction (Section 70100-70183 Traffic Stripe)	Alabama DOT 2023	https://alletting.dot.state.al.us/Docs/Standard_Drawings/StdSpecialDrawingsEnglish2023.html	Note indicates that striping width is noted by the pay item in the plans.
Alaska	2016 Alaska Traffic Manual (Chapter 3B: Pavement and Curb Markings)	Alaska DOT 2016	https://dot.alaska.gov/stwddes/dcstraffic/assets/pdf/atm/current/2016atms_inc.pdf	No amendments to national MUTCD regarding width of pavement striping or use of striping on low volume roads.
Alaska	Standard Specifications for Highway Construction: 2020 Edition (Section 670: Traffic Markings)	Alaska DOT 2020	https://dot.alaska.gov/stwddes/dcsspecs/assets/pdf/hwyspecs/sshc2020.pdf	Section 670-3.01 (Construction Requirements) indicates the use of 4-in width for striping.
Arizona	Arizona Supplement to the Manual on Uniform Traffic Control Devices for Streets and Highways (Chapter 3B: Pavement and Curb Markings)	Arizona DOT 2012	https://azdot.gov/sites/default/files/2019/07/arizona-supplement-to-the-manual-on-uniform-traffic-control-devices-2009-mutcd-edition.pdf	No amendments to national MUTCD regarding width of pavement striping or use of striping on low volume roads.
Arizona	Standard Specifications for Road and Bridge Construction (Section 708: Waterborne Paint)	Arizona DOT 2021	https://azdot.gov/sites/default/files/media/2021/04/2021_Standard_Specifications_for_Road_and_Bridge_Construction_PC.pdf	Section 708-4 (Method of Measurement) indicates that measurement for payment of paint for pavement markings is based on a width of 4 in, with an adjustment for other widths.

State	Title	Reference	URL	Summary
Arkansas	Standard Specifications for Highway Construction (Section 718: Reflectorized Paint Pavement Marking)	Arkansas State Highway and Transportation Department 2014	https://www.ardot.gov/wp-content/uploads/2020/10/2014SpecBook.pdf	Section 718.01 (Description) indicates that the MUTCD should be followed unless modified by specifications. Section 718.03 (Construction Requirements) provides an application rate based on a 4-in wide stripe.
Arkansas	Standard Roadway Drawings (PM-1: Pavement Marking Details)	Arkansas DOT 2023	https://www.ardot.gov/divisions/roadway-design/standard-roadway-drawings/	Note indicates that striping widths are provided on striping details.
California	California Manual on Uniform Traffic Control Devices	Caltrans 2014	https://dot.ca.gov/-/media/dot-media/programs/safety-programs/documents/ca-mutcd/rev7/1-13-camutcd2014-intro-rev7.pdf	State MUTCD indicates no changes to language from national MUTCD regarding warrants for edge line and center line markings.
California	Implementation of Six-Inch Wide Traffic Lines and Discontinuing Use of Non-Reflective Raised Pavement Markers (Memorandum)	Caltrans 2017	https://dot.ca.gov/-/media/dot-media/programs/traffic-operations/documents/memos-letters/6-in-wide-traffic-lines_05-19-17-memo.pdf	Memorandum describes policy change for pavement markings. All longitudinal line markings must be 6 in wide.
California	Standard Plans (A20A through A20D: Pavement Markers and Traffic Lines – Typical Details)	Caltrans 2023	https://dot.ca.gov/-/media/dot-media/programs/design/documents/locked-2023-std-plans-dor-a11y.pdf	Standard drawings show 6-in width for all lane markings.
Colorado	Colorado Supplement to the Federal Manual on Uniform Traffic Control Devices 2009	Colorado DOT 2022	https://www.codot.gov/safety/traffic-safety/assets/documents/mutcd/MUTCD_2003_Colorado_Supplement.pdf	State MUTCD supplement indicates no changes to language from national MUTCD regarding warrants for edge line and center line markings.

State	Title	Reference	URL	Summary
Colorado	Standard Specifications for Road and Bridge Construction (Section 627: Pavement Marking)	Colorado DOT 2023	https://www.codot.gov/business/designsupport/cdot-construction-specifications/2023-construction-specifications/2023-specs-book/2023-cdot-specs-book.pdf	According to Table 627-1, the width of paint striping should be within 0.25 in of the width shown on the plans.
Connecticut	Traffic Engineering Standard Drawings (TR-1210_01 through TR-1210_09)	Connecticut DOT 2023	https://portal.ct.gov/DOT/Traffic-Standard-Drawings/TRAFFIC-STANDARD-GUIDE-SHEETS-DETAILS	Standards indicate that center line and edge line markings are 4 in wide. Broken lane lines on divided highways are 6 in wide.
Delaware	Interim Guidance; Part 3, Markings Section 3A.06 Regarding Pavement Marking Widths (MEMORANDUM)	Delaware DOT 2022	https://deldot.gov/Publications/manuals/de_mutcd/pdfs/InterimGuidance_6InchMarkings.pdf?cache=1697058285945?cache=1697058546794	This Interim Guidance to the Delaware MUTCD indicates that pavement marking widths should be 6 in for normal markings and 12 in for wide markings on state-maintained roadways. Previous widths were 5 in and 10 in, respectively.
District of Columbia	Standard Drawings (612.05: Typical Pavement Marking Applications and Intersection Signing)	District of Columbia DOT 2020	https://ddotwiki.atlassian.net/wiki/spaces/COM/pages/2069271070/Standards+and+Manuals#StandardsandManuals-StandardDrawings	Width of edge line and center line markings is 4 in.
Florida	Manual of Uniform Minimum Standards for Design, Construction and Maintenance for Streets and Highways (Chapter 18: Signing and Marking)	Florida DOT 2018	https://fdotwww.blob.core.windows.net/sitefinity/docs/default-source/roadway/floridagreenbook/2018-florida-greenbook.pdf?	Edge line, center line, and lane separation lines should be 6 in wide.

State	Title	Reference	URL	Summary
Florida	FY 2023-24 Standard Plans (711-001: Pavement Markings)	Florida DOT 2023	https://fdotwww.blob.core.windows.net/sitefinity/docs/default-source/design/standardplans/2024/rstandardplansfy2023-24dfcf0e28-6815-4df9-85ae-83b63e38f135.pdf?sfvrsn=2782909d_1	Width of edge line and center line markings is 6 in.
Georgia	Standard Specifications Construction of Transportation Systems (Section 652: Painting Traffic Stripe)	Georgia DOT 2021	https://www.dot.ga.gov/PartnerSmart/Business/Source/specs/2021StandardSpecifications.pdf	Section 652.2.05B provides application rates for a 5-in wide traffic stripe and indicates that the application rate should be scaled proportionately for other stripe widths.
Georgia	2024 Construction Standards and Details (T-11A Pavement Marking Placement Non-Limited Access Roadway and T-11B Pavement Marking Placement Limited Access Roadway)	Georgia DOT 2023a	http://mydocs.dot.ga.gov/info/gdotpubs/ConstructionStandardsAndDetails/Forms/AllItems.aspx	Edge line, center line, and lane separation lines are 5 in wide.
Georgia	Signing and Marking Design Guidelines (Chapter 12: Pavement Markings Designs Standards)	Georgia DOT 2023b	https://www.dot.ga.gov/PartnerSmart/DesignManuals/smguide/GDOT%20SIGNING%20AND%20MARKING%20DESIGN%20GUIDELINES.pdf	Edge lines are required on all paved roadways.
Hawaii	2005 Standard Specifications (Section 629: Pavement Markings)	Hawaii DOT 2005	https://hidot.hawaii.gov/highways/s2005-standard-specifications/2005-standard-specifications/	Section 629.03(C).2 provides application rate for a single 4-in stripe.

State	Title	Reference	URL	Summary
Idaho	Traffic Manual: Idaho Supplementary Guidance to the MUTCD	Idaho Transportation Department 2020	https://apps.itd.idaho.gov/apps/manuals/TrafficManual.pdf	State MUTCD supplement indicates no changes to language from national MUTCD regarding warrants for edge line and center line markings or pavement marking widths.
Idaho	Standard Drawings (630-1: Pavement Markings)	Idaho Transportation Department 2023	https://apps.itd.idaho.gov/apps/StandardDrawings/standarddrawings.htm	Width of normal line is 4 in to 6 in. Width of wide line is twice the width of normal line.
Illinois	Illinois Supplement to the Manual on Uniform Traffic Control Devices	Illinois DOT 2021	https://public.powerdms.com/IDOT/documents/2010838/Illinois%20Supplement%20to%20the%20Manual%20on%20Uniform%20Traffic%20Control%20Devices%2C%20Revision%203	State MUTCD supplement indicates no revisions to Part 3 (Markings).
Illinois	Highway Standards and District Specific Standards (Standard 780001-05: Typical Pavement Markings)	Illinois DOT 2023	https://idot.illinois.gov/doing-business/procurements/engineering-architectural-professional-services/consultant-resources/highways/manuals-and-guides/highway-standards-and-district-specific-standards.html	Width of edge line and center line markings is 4 in.
Indiana	2011 Indiana Manual on Uniform Traffic Control Devices Revisions 1 & 2 & 3	Indiana DOT 2011	https://www.in.gov/dot/div/contracts/design/mutcd/2011rev3MUTCD.htm	State MUTCD indicates no changes to language from national MUTCD regarding warrants for edge line and center line markings and pavement marking widths.

State	Title	Reference	URL	Summary
Indiana	Indiana Design Manual (Chapter 502: Traffic Design)	Indiana DOT 2022	https://www.in.gov/dot/div/contracts/design/IDM.htm	As shown in Figure 502-2B, center line and edge line markings on Indiana DOT roadways are 6 in wide. Center line and edge line markings on Local Public Agency (LPA) roadways are 4 in wide. In Section 502-2.02, warrants for center line markings on non-INDOT highways are provided. For paved low volume roads on non-INDOT roadways, center lines are recommended when the ADT is at least 300 vpd.
Iowa	Traffic and Safety Manual (Chapter 3: Pavement Markings)	Iowa DOT 2022	https://iowadot.gov/traffic/Library/Traffic-and-Safety-Manual	As noted in Section 3B (Pavement Markings Standards), center line, edge line, and lane line markings are 4 in wide.
Kansas	Standard Specifications for State Road and Bridge Construction (Section 807: Painted Pavement Marking)	Kansas DOT 2015	https://www.ksdot.gov/bureaus/burConsMain/specprov/2015specprov.asp	Pavement markings should be applied as indicated in Contract Documents. Width of pavement marking is incorporated into the pay item. Application rate is provided for 4-in line, and application rate should be increased proportionally for other widths.

State	Title	Reference	URL	Summary
Kentucky	Traffic Operations Guidance Manual (Chapter 500: Pavement Markings and Delineation)	Commonwealth of Kentucky Transportation Cabinet 2021	https://transportation.ky.gov/Organizational-Resources/Policy%20Manuals%20Library/Traffic%20Operations.pdf	As noted in Section TO-503 (Striping), 6-in striping is required for all interstates, parkways, ramps, and other highways on the State Primary Road System (SPRS). For two-lane highways not on the SPRS, 6-in striping should be used if the traveled way width is at least 20 ft and the ADT is at least 1,000 vpd. Striping on other roadways may be 4 in wide. For two-lane two-way roadways width less than 16 ft, center lines should not be placed. However, edge line markings should be provided unless division approval is received to omit them. For two-lane highways with traveled way widths greater than or equal to 16 ft and less than 20 ft, edge line markings should be provided unless division approval is received to omit them. Either center line or edge line striping should be provided based on engineering judgement. For two-lane highways with a traveled way width of at least 20 ft, center line striping is required. Edge line markings are also required if the ADT is at least 1,000 vpd. Edge line markings are not required if the ADT is less than 1,000 vpd and the roadway is not on the SPRS.
Louisiana	Standard Plans (PM-01: Center line and Edgeline Markings)	Louisiana Department of Transportation 2023	http://wwwsp.dotd.la.gov/Inside_LaDOTD/Divisions/Engineering/Standard_Plans/Pages/default.aspx	Width of edge lines, center lines, and edge lines is 4 in. Edge lines should be installed on all roadways. Center lines should be installed on roadways with a traveled way width of at least 16 ft.
Maine	Maine DOT Standard Details (627(01-05): Pavement Markings)	Maine DOT 2020a	https://www.maine.gov/mdot/contractors/publications/standarddetail/docs/2020/2020-STANDARD_DETAILS.pdf	Pavement markings shall be placed in accordance with national MUTCD. Width of striping on Interstates shall be 6 in.

State	Title	Reference	URL	Summary
Maine	Maine DOT Standard Specifications (Section 627: Pavement Markings)	Maine DOT 2020b	https://www.maine.gov/mdot/contractors/publications/standardspec/	Pavement markings shall be placed in accordance with national MUTCD (Section 627.04). On non-Interstate roadways, width of stripe shall be 4 in unless stated otherwise on the plans. On Interstate highways and controlled access divided highways, width of stripe shall be 6 in.
Maryland	Maryland Manual on Uniform Traffic Control Devices for Streets and Highways 2011 Edition	Maryland State Highway Administration 2011	https://www.roads.maryland.gov/mdotsha/pages/Index.aspx?PageId=835	For normal lines, width of stripe shall be 5 in on roadways that are owned, operated, and maintained by the State. State MUTCD indicates no changes to language from national MUTCD regarding warrants for edge line and center line markings.
Massachusetts	The Massachusetts Amendments to the 2009 Manual on Uniform Traffic Control Devices for Streets and Highways (Part 3: Markings)	Massachusetts DOT 2022	https://www.mass.gov/lists/mutcd-massachusetts-amendments	Width of all normal lines is 6 in (12 in for wide lines) for roads on the National Highway System and for any roads with a speed limit of 45 mph or higher. State MUTCD supplement indicates no changes to language from national MUTCD regarding warrants for edge line and center line markings.
Michigan	Michigan Manual on Uniform Traffic Control Devices (Part 3: Markings)	Michigan DOT 2022	https://mdotjboss.state.mi.us/TSSD/getCategoryDocuments.htm?categoryPrjNumbers=1403854,1403855&category=MMUTCD	State MUTCD supplement indicates no changes to language from national MUTCD regarding warrants for edge line and center line markings or pavement marking widths.
Michigan	6-Inch Pavement Markings	Michigan DOT 2024	https://www.michigan.gov/mdot/travel/safety/road-users/six-inch-wide-pavement-markings	Web article that indicates MDOT is in the process of switching to 6-in wide edge lines. Michigan switched to 6-in wide lane striping on freeways in 20202. In 2021, MDOT began the process of switching white and yellow lane lines on non-freeways to a width of 6 in.

State	Title	Reference	URL	Summary
Minnesota	Minnesota Manual on Uniform Traffic Control Devices	Minnesota DOT 2023a	https://dot.state.mn.us/trafficeng/publ/mutcd/index.html	State MUTCD indicates no changes to language from national MUTCD regarding warrants for edge line and center line markings or pavement marking widths.
Minnesota	Traffic Engineering Manual (7-5.02: Marking Widths and Patterns)	Minnesota DOT 2023b	https://dot.state.mn.us/trafficeng/publ/tem/index.html	Required width for edge line markings is 6 in for installations in 2022 or later. Other longitudinal lines may be 4 to 6 in wide.
Mississippi	Roadway Design Standard Drawings (PM-1: Pavement Marking Details for 2-Lane and 4-Lane Divided Roadways)	Mississippi DOT 2017	https://mdot.ms.gov/documents/Roadway%20Design/Standards/Drawings/Roadway%20Design%20Standard%20Drawings.pdf	Standard drawing shows 6-in marking width for both edge line and center line markings on 2-lane and 4-lane divided highways.
Missouri	Engineering Policy Guide (EPG) (620: Pavement Marking)	Missouri DOT 2017	https://epg.modot.org/index.php/Category:620_Pavement_Marking	White edge lines and center lines and yellow edge lines on all major routes should be 6 in wide and all other markings should be 4 in wide. Major roads and regionally significant roads are striped annually. A maximum of 50 percent of minor roads with AADT of at least 400 vpd are striped annually. A maximum of 33 percent of minor roads with AADT less than 400 vpd are striped annually.
Montana	Montana Traffic Engineering Manual (Chapter 19: Pavement Markings)	Montana DOT 2009	https://www.mdt.mt.gov/other/webdata/external/traffic/manual/chapter_19.pdf	Solid white, reflectorized edge lines, 4-in wide, should be used at locations with a paved width of at least 20 ft for any ADT. Consideration should be given to the application of wider edge lines at locations that require more delineation of the edge of pavement. Wide edge lines may help to reduce run-off-road crashes at horizontal curves.

State	Title	Reference	URL	Summary
Nebraska	Nebraska DOT Standard Specifications for Highway Construction (Section 423: Permanent Pavement Marking)	Nebraska DOT 2017	https://dot.nebraska.gov/media/g4qp4y0d/2017-specbook.pdf	Section 423 (Permanent Pavement Marking) does not specify warrants for edge line and center line markings or pavement marking widths. Nebraska DOT follows the national MUTCD.
Nebraska	Nebraska Supplement to the MUTCD	Nebraska DOT 2019	https://dot.nebraska.gov/media/j0klgqug/ne-mutcd-2019.pdf	State MUTCD indicates no changes to language from national MUTCD regarding warrants for edge line and center line markings or pavement marking widths.
Nevada	Nevada Standard Specifications for Road and Bridge Construction (Section 634: Pavement Marking Film)	Nevada DOT 2014	https://www.dot.nv.gov/home/showpublisheddocument/6916/636257041112930000	According to Section 634.03.01 (Construction – General), pavement markings should be 4-in wide, unless a different width is specified.

State	Title	Reference	URL	Summary
Nevada	Nevada Signing, Striping, and Traffic Control Design Guide (Section 5)	Nevada DOT 2022	https://www.dot.nv.gov/home/showpublisheddocument/20978/638054014494070000	Section 5 (Striping and Pavement Markers), states that 8-in edge line striping is utilized on interstates and freeways. In 2021, a statewide policy was approved to apply 6-in edge line striping for rural roadways with an AADT higher than 400 vpd,for rural roadways with speeds exceeding 40 mph, and for list of specified state routes. Edge line striping for all other state routes is 4 in wide. Section 5 also states that switching from 4-in to 6-in edge lines on rural roadways has led to reductions in all types of crashes. The center line width is 8 in on interstates and freeways and 4 in on all other roadways. The use of center lines is required for all paved urban arterials and collectors with a paved roadway width of at least 20 ft and ADT of at least 6,000 vpd. Nevada DOT has adopted the national MUTCD along with a sign supplement.
New Hampshire	New Hampshire Standard Specifications for Road and Bridge Construction (Section 632: Retroreflective Pavement Markings)	New Hampshire DOT 2016	https://www.dot.nh.gov/about-nh-dot/divisions-bureaus-districts/highway-design/highway-standard-specifications/2016	According to Section 3.1.4 (Construction Requirements), unless otherwise directed, edge lines shall be 6-in wide on Interstates, and center lines and edge lines shall be 4-in wide on all other applications.
New Jersey	New Jersey Standard Construction Details – Roadway, Traffic Control, Bridge	New Jersey DOT 2016	https://www.nj.gov/transportation/eng/CADD/v8/pdf/StandConstDetails.pdf	This document addresses temporary pavement markings only. New Jersey DOT follows guidance in the national MUTCD for edge line striping width.

State	Title	Reference	URL	Summary
New Jersey	New Jersey Standard Specifications for Road and Bridge Construction	New Jersey DOT 2019	https://www.nj.gov/transportation/eng/specs/2019/pdf/StandSpecRoadBridg2019_20231222.pdf	Edge line striping width is not mentioned in the New Jersey Standard Specifications. New Jersey DOT follows guidance in the national MUTCD.
New Mexico	New Mexico Standard Specifications for Highway and Bridge Construction	New Mexico DOT 2019	https://realfilef260a66b364d453e91ff9b3fedd494dc.s3.amazonaws.com/fcd4d178-70ff-4a21-8ea5-2bede74c831b?AWSAccessKeyId=AKIAJBKPT2UF7EZ6B7YA&Expires=1705840492&Signature=8QJ5JTgHZBOE9da4meKqghb0weg%3D&response-content-disposition=inline%3B%20filename%3D%222019%20Specs%20for%20Highway%20and%20Bridge%20Construction.pdf%22&response-content-type=application%2Fpdf	Edge line striping width is not mentioned. New Mexico DOT follows guidance in the national MUTCD.

State	Title	Reference	URL	Summary
New Mexico	New Mexico Standard Drawings for Highway and Bridge Construction	New Mexico DOT 2019	https://realfilef260a66b364d453e91ff9b3fedd494dc.s3.amazonaws.com/8bdb30ed-466c-4a57-96f7-c3d172b1524d?AWSAccessKeyId=AKIAJBKPT2UF7EZ6B7YA&Expires=1705840653&Signature=ELhGCLBI6p%2BIH79vy7srgPsz9hg%3D&response-content-disposition=inline%3B%20filename%3D%222019%20Standard%20Drawings%20for%20Highway%20and%20Bridge%20Construction%20%28Update%20October%202023%29.pdf%22&response-content-type=application%2Fpdf	Edge line striping width is not mentioned. New Mexico DOT follows guidance in the national MUTCD.
New York State	New York State Supplement to the MUTCD (Part3 : Markings)	New York State DOT 2011	https://www.dot.ny.gov/divisions/operating/oom/transportation-systems/repository/B-2011Supplement-adopted.pdf	The Supplement does not address center line or edge line pavement marking width. Section 3B.07 (Warrants for Use of Edge Lines), states that edge line markings may be applied on other paved streets or highways irrespective of the use of center line pavement markings.

State	Title	Reference	URL	Summary
New York State	New York State Engineering Instruction EI 18-008	New York State DOT 2018	https://www.dot.ny.gov/portal/pls/portal/mexis_app.pa_ei_eb_admin_app.show_pdf?id=12732	This Engineering Instruction states that edge lines 6-in wide should be used on all rural high-speed highway segments with posted speed limits of 45 mph and higher. It also states that wider edge line pavement markings have been shown to have a positive safety benefit on rural two-lane two-way highways and lead to a high benefit–cost ratio on these roadways. The Engineering Instruction specifies that it applies only to white edge lines because there are two yellow center line markings and center line rumble strips are typically utilized on high-speed highways.
New York State	New York State Pavement Marking Details Standard Sheet (685-01)	New York State DOT 2023	https://www.dot.ny.gov/main/business-center/engineering/cadd-info/drawings/standard-sheets-us-repository/685-01_050213.pdf	Normal pavement marking lines shall be 6 in wide on freeways and expressways and at locations noted in contract documents. Normal pavement marking lines shall be 4 in wide elsewhere.
North Carolina	North Carolina Supplement to the MUTCD	North Carolina DOT 2009	https://connect.ncdot.gov/resources/safety/trafficsafetyresources/2009%20nc%20supplement%20to%20mutcd.pdf	State MUTCD indicates no changes to language from national MUTCD regarding warrants for edge line and center line markings or pavement marking widths.
North Carolina	North Carolina Standard Specifications for Roads and Structures (Section 1205: Pavement Marking General Requirements)	North Carolina DOT 2024	https://connect.ncdot.gov/resources/Specifications/2024StandardSpecifications/2024%20Standard%20Specifications%20for%20Roads%20and%20Structures.pdf	Section 1205 (Pavement Marking General Requirements) does not specify warrants for edge line and center line markings or pavement marking widths.
North Dakota	North Dakota Supplement to the MUTCD	North Dakota DOT n.d.	Not available online	The North Dakota Supplement to the MUTCD is not available online. Their Design Manual (North Dakota DOT 2024) does not address warrants for edge line or center line markings or pavement marking widths.

State	Title	Reference	URL	Summary
Ohio	Ohio Manual of Uniform Traffic Control Devices	Ohio DOT 2012	https://www.dot.state.oh.us/roadway/omutcd/Documents/2012%20OMUTCD%20-%20Pt.%203.pdf	No amendments to national MUTCD regarding width of edge line or center line pavement markings or warrants for edge line pavement markings. The Ohio MUTCD provides the following standard regarding warrants for center line pavement markings (follows national MUTCD language): "Center line markings shall be placed on all paved urban arterials and collectors that have a traveled way of 20 ft or more in width and an ADT of 6,000 vpd or greater. Center line markings shall also be placed on all paved two-way streets or highways that have three or more lanes for moving motor vehicle traffic."
Ohio	Ohio Traffic Engineering Manual	Ohio DOT 2024	https://www.transportation.ohio.gov/working/engineering/roadway/manuals-standards/tem/03#301PAVEMENTCURBMARKINGS	Center line markings should be 4 in wide. Edge line markings should be 6 in wide on interstates, freeways and expressways, multilane divided highways, multilane undivided highways, and two-lane rural highways. All other highways should have 4-in edge lines. Wide lines (double width) may be placed for greater emphasis.
Oklahoma	Oklahoma Supplement to the MUTCD	Oklahoma DOT n.d.	Not available online	The Oklahoma Supplement to the MUTCD is not available online.
Oregon	Oregon Supplement to the MUTCD	Oregon DOT 2020	https://www.oregon.gov/ODOT/Engineering/Documents_TrafficStandards/MUTCD-OR-Supplement.pdf	Part 3 (Markings) only addresses stop and yield lines and crosswalk markings. The Supplement indicates no changes to language from the national MUTCD regarding warrants for edge line and center line markings or pavement marking widths.

State	Title	Reference	URL	Summary
Pennsylvania	Alternative Statewide Policies for Line-Painting on Low-Volume Roads	Pennsylvania DOT 2016	-	Provides warrants for pavement markings on low volume roads based on ADT and district.
Pennsylvania	Pennsylvania Supplement to the MUTCD; Chapter 212, Title 67 – Pennsylvania Code – Official Traffic Control Devices	Commonwealth of Pennsylvania 2023	https://pacodeandbulletin.gov/Display/pacode?file=/secure/pacode/data/067/chapter212/chap212toc.html	The Supplement indicates no changes to language from the national MUTCD regarding warrants for edge line and center line markings or pavement marking widths.
Pennsylvania	Pennsylvania Pavement Marking and Signing Standards (2013 Edition) (PUB 111)	Pennsylvania DOT 2021	https://www.dot.state.pa.us/public/PubsForms/Publications/PUB%20111.pdf	For expressways and freeways, edge lines should be a minimum of 4 in wide. For other roadways, edge lines should be a minimum of 4 in wide; and use of edge lines is not mandated for curb and gutter locations.
Rhode Island	Rhode Island Traffic Design Manual (Section 2.0: Pavement Markings)	Rhode Island DOT 2004	https://www.dot.ri.gov/documents/doingbusiness/trafdesignmanual.pdf	On freeways and expressways, all edge lines should be 6 in wide. On all other roadways, white edge lines should be 6 in wide, and yellow center and edge lines should be 4 in wide.
South Carolina	South Carolina Supplement to the MUTCD	South Carolina DOT 2011	https://www.scdot.org/business/pdf/accessMgt/trafficEngineering/supplement_mutcd.pdf	This supplement states that all pavement markings should comply with the national MUTCD. Nothing in the supplement changes any of the requirements of the MUTCD.
South Carolina	South Carolina Standard Drawings (625-105-00: Pavement Edge Marking and Stop Limits)	South Carolina DOT 2013	https://www.scdot.org/business/standard-drawings.aspx	Notes on this drawing for freeways indicate that all pavement edge lines should be 6 in wide, and the right edge line should be reflectorized white in color.
South Dakota	South Dakota Standard Plates (Series 633: Pavement Marking	South Dakota DOT 2024	https://apps.sd.gov/HP20StandardPlates/	The South Dakota Standard Plate for Pavement Marking shows a 4-in edge line.

State	Title	Reference	URL	Summary
Tennessee	Rules of Tennessee Department of Transportation (Chapter 1680-03-01: Adoption of the Tennessee Manual on Uniform Traffic Control Devices for Streets and Highways)	Tennessee DOT 2012	https://publications.tnsosfiles.com/rules/1680/1680-03/1680-03-01.20120729.pdf	Tennessee has adopted the national MUTCD with some noted exceptions, none of which concern the warrants for or widths of center line or edge line pavement markings.
Tennessee	Tennessee Standard Drawings (T-M-2: Details of Pavement Markings for Conventional Roads	Tennessee DOT 2019	https://www.tn.gov/content/dam/tn/tdot/roadway-design/documents/standard_drawings/roadway_standard_drawings/current/design---traffic-control/pavement-markings/TM2.pdf	This standard drawing states that edge lines are not required at locations with a pavement width less than 16 ft or on curb and gutter sections unless directed in plans.
Texas	Texas MUTCD; Part 3; Markings	Texas DOT 2011	https://ftp.txdot.gov/pub/txdot-info/trf/tmutcd/2011-rev-2/3.pdf	No amendments to national MUTCD regarding width of edge line or center line pavement markings or warrants for edge line pavement markings. The Texas MUTCD provides the following standard regarding warrants for center line pavement markings (follows national MUTCD): "Center line markings shall be placed on all paved urban arterials and collectors that have a traveled way of 20 ft or more in width and an ADT of 6,000 vpd or greater. Center line markings shall also be placed on all paved two-way streets or highways that have three or more lanes for moving motor vehicle traffic."

State	Title	Reference	URL	Summary
Texas	Traffic Safety Division Standard (PM(1)-22: Typical Standard Pavement Markings)	Texas DOT 2022	https://ftp.dot.state.tx.us/pub/txdot-info/cmd/cserve/standard/traffic/pm1-22.pdf	The typical standard for pavement markings shows 6-in edge lines and 6-in center lines.
Utah	Utah MUTCD 2009 Edition	Utah DOT 2011	https://drive.google.com/file/d/1JyNnvMXo5LgvhvSltSOh5miCxD84PSdJ/view	The Utah MUTCD follows the national MUTCD in terms of warrants for use of edge lines. In Section 3B.06 (Edge Line Pavement Markings), it does not recommend a specific width of edge line pavement marking, but states that "right edge line pavement markings shall consist of a normal solid white line to delineate the right-hand edge of the roadway." The Utah MUTCD also states that "wide solid edge line markings may be used for greater emphasis."
Utah	Utah Standard Specification Book	Utah DOT 2024	https://drive.google.com/drive/folders/1UnupxBjh9sDCnRWlW9Yc6X2wyMF5b6Tj	The Standard Specifications do not specify edge line or center line pavement marking width.
Vermont	Vermont State Design Standards	Vermont DOT 1997	https://vtrans.vermont.gov/sites/aot/files/highway/documents/publications/VermontStateDesignStandards.pdf	The design standards state that the use of safety features such as guardrail, signing, marking, etc. should be considered for all projects. No pavement marking width is specified in the design standards. Vermont follows the national MUTCD.

State	Title	Reference	URL	Summary
Virginia	Virginia Supplement to the MUTCD	Virginia DOT 2013	https://www.vdot.virginia.gov/media/vdotvirginiagov/doing-business/technical-guidance-and-support/technical-guidance-documents/traffic-engineering/Revision_1_Entire_Supplement.pdf	A width of 6 in is required for all lane lines and edge lines on freeways. The minimum width of line markings on other types of facilities is 4 in; however, 6-in wide line markings may be used on other types of facilities based on engineering judgement. The Virginia Supplement also adds the following: "Where a paved shoulder is provided, the edge line, if used, shall be placed in the travel lane and not in the paved shoulder area." The use of center line markings is required for all undivided limited access highways, bi-directional multi-lane roadways, and all other paved roadways (excluding residential streets) with a pavement width of at least 18 ft and traffic volumes of at least 500 vpd.
Washington	Washington State DOT Standard Plans (M-20.10-04: Longitudinal Marking Patterns)	Washington State DOT 2023	https://wsdot.wa.gov/publications/fulltext/Standards/Standard-Plan-Manual-October2023.pdf	The Washington DOT standard plans for longitudinal marking patterns show 4-in center line and edge line markings; and 8-in "wide" edge line markings as an option for roundabout applications.
Washington	Washington Administrative Code; Chapter 468-95; Manual on Uniform Traffic Control Devices for Streets and Highways	Washington State Legislature 2023	https://apps.leg.wa.gov/WAC/default.aspx?cite=468-95	The Washington State Supplement to the MUTCD states that edge lines are required on all interstate highways, and rural multilane divided highways; and on all principal arterials and minor arterials located in urbanized areas, except on roadways with curb or sidewalk. Edge lines are also required on paved rural arterials with a minimum travelway width of 20 ft and ADT of at least 6,000 vpd. Edge lines also may be utilized on other types of roads. There are no amendments to the national MUTCD regarding width of edge line or center line pavement marking.

State	Title	Reference	URL	Summary
West Virginia	West Virginia Manual on Temporary Traffic Control for Streets and Highways	West Virginia DOT 2006	https://transportation.wv.gov/highways/traffic/Documents/TemporaryTrafficControlManual2006.pdf	The West Virginia supplement to the MUTCD is entirely focused on temporary traffic control. Thus, there are no amendments to the national MUTCD regarding width of edge line or center line pavement marking.
West Virginia	West Virginia Standard Details Book Volume II: Signing, Signals, Lighting, Markings, and ITS (TEM-2: Typical Pavement Markings)	West Virginia DOT 2019	https://transportation.wv.gov/highways/engineering/StandardDetails/Vol2/Std%20Dtls%20Vol%20II%202019-01-01.pdf	The West Virginia standard details sheets on Typical Pavement Markings show 6-in edge line and center line pavement markings.
Wisconsin	Wisconsin MUTCD Part 3: Markings	Wisconsin DOT 2017	https://wisconsindot.gov/dtsdManuals/traffic-ops/manuals-and-standards/wmutcd/mutcd-ch03.pdf	The Wisconsin MUTCD does not deviate from the national MUTCD regarding width of edge line or center line pavement marking or warrants for edge line pavement markings. The Wisconsin MUTCD provides the following standard regarding warrants for center line pavement markings (follows national MUTCD): "Center line markings shall be placed on all paved urban arterials and collectors that have a traveled way of 20 ft or more in width and an ADT of 6,000 vpd or greater. Center line markings shall also be placed on all paved two-way streets or highways that have three or more lanes for moving motor vehicle traffic."
Wisconsin	6 Inch Pavement Marking Effective with November 2023 LET Projects. Memorandum	Wisconsin DOT 2023	-	Memorandum that describes policy change to switch from 4-in to 6-in markings for US highways, Interstates, and state highways in November 2023.

State	Title	Reference	URL	Summary
Wyoming	Wyoming Pavement Marking Manual	Wyoming DOT 2012a	https://www.dot.state.wy.us/files/live/sites/wydot/files/shared/Traffic%20data/Pavement%20Marking%20Manual.pdf	The Pavement Marking Manual states that a normal longitudinal line is 4 to 6 in wide, and the standard width is 4 in. Center line markings are required on all undivided two-way highways on the state system with a width of at least 20 ft, regardless of ADT. Edge line markings should not be placed if the travel lane is less than 10 ft wide unless approved by the State Traffic Engineer.
Wyoming	Wyoming Standard Plans (799-1A: Pavement Striping)	Wyoming DOT 2012b	https://www.dot.state.wy.us/files/live/sites/wydot/files/shared/Engineering_Services/Standard%20Plans/799-1A%20(DEC_2012).pdf	Wyoming has adopted the national MUTCD. Wyoming's standard plans for pavement striping on a freeway near an interchange show 4-in edge lines.

Appendix B: Example Interview Questions

This Appendix provides lists of example questions for state DOT interviews. These questions will be customized for each DOT.

Interview questions for State DOTs with 4 in Markings

1. What are your DOT's existing policies regarding the use of wider pavement markings and pavement markings on low volume roads?
2. What type of material does your DOT use for pavement markings?
3. Has your DOT performed any studies evaluating the performance of wider pavement markings or use of pavement markings on low volume roads?
4. How many miles of roadway does your DOT manage/maintain? Does your DOT contract out the striping work or perform it in-house?
5. How frequently does your DOT stripe roadways? Does this frequency vary based on roadway type or other factors?
6. What strategies does your DOT use to optimize striping capacity?
7. Do striping practices within your state vary between rural and urban areas?
8. To what extent does your DOT use pavement markings on low volume roads?
9. What other strategies does your DOT implement to try to reduce run-off-road crashes?
10. Is your DOT considering the use of wider pavement markings in the future?
11. What are some of the challenges your DOT would face if a change to wider markings were to be considered?
12. Is your DOT considering any other changes to its pavement marking policies in the future?

Interview questions for State DOTs with 5 in or Wider Markings

1. What are your DOT's existing policies regarding the use of wider pavement markings and pavement markings on low volume roads?
2. What type of material does your DOT use for pavement markings?
3. To what extent does your DOT use wider pavement markings? Are wider pavement markings used more frequently on certain roadways based on any particular characteristics (e.g., AADT, functional class, potential for run-off-road crashes)?
4. When did your DOT start using wider pavement markings?
5. Has your DOT performed any studies evaluating the performance of wider pavement markings or use of pavement markings on low volume roads?
6. Based on your DOT's experience, how does the service life of 6-in markings compare with the service life of 4-in markings?
7. How many miles of roadway does your DOT manage/maintain? Does your DOT contract out the striping work or perform it in-house?
8. How frequently does your DOT stripe roadways? Does this frequency vary based on roadway type or other factors?

9. How has the use of wider markings affected your DOT's overall striping capacity? What strategies does your DOT use to address concerns regarding striping capacity?
10. Do striping practices within your state vary between rural and urban areas?
11. Has your DOT encountered any challenges or issues with using wider pavement markings?
12. To what extent does your DOT use pavement markings on low volume roads?
13. Based on your DOT's experience, does your DOT have any implementation suggestions regarding the use of wider striping or striping on low volume roads?
14. What other strategies does your DOT implement to try to reduce run-off-road crashes?
15. Is your DOT considering any changes to its pavement marking policies in the future?