Texas Transportation Institute

The Use of Wider Longitudinal Pavement Markings

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16. Abstract

Over the past two decades, as more knowledge has been gained about driver visibility needs and the aging driver population trends, some highway agencies have begun to use longitudinal pavement markings that are wider than the 4-inch minimum for standard centerline, edge line, and/or lane line applications. The overall goal of this study was to identify information pertaining to the use of wider markings by highway agencies in the United States, Canada and worldwide and combine with the technical literature to provide a comprehensive report detailing the use and benefits of wider markings. Research activities included surveys and reviews of technical literature. A survey was administered to roadway agencies in the United States and Canada in Spring 2001. This survey revealed that a number of these agencies are using wider pavement markings, although levels of implementation and reasons for using them vary. A separate but similar survey was administered to highway personnel worldwide. A review of the research literature has identified five main methods for evaluating the effectiveness of wider pavement markings. Traditional measures of effectiveness have centered on crash evaluations and service life evaluations mainly because the results can readily be used in benefit/cost evaluations. Unfortunately, conclusive crash reduction or improved service life data does not exist in the literature or within highway agencies. Evidence has suggested that because conclusive benefit/cost data are not obtainable, highway agencies and researchers alike are turning to indirect (or implied) safety measures to justify the use of wider markings. These indirect measures include: driver opinion surveys/comments, visibility measures, and "intermediate" or "surrogate" safety measures. Although very little research exists, the available scientific evidence suggests that the greatest benefit that wider markings may provide is improved peripheral visibility, which is related to primary driving tasks such as lane keeping. This paper presents the survey results and a critical review of the literature regarding wider pavement markings in the United States, Canada, and worldwide. Conclusions and suggestions have been made as to the use of wider markings by highway agencies and future research endeavors.

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THE USE OF WIDER LONGITUDINAL PAVEMENT MARKINGS

Final Report

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EXECUTIVE SUMMARY

Over the past two decades, as researchers have gained more knowledge about driver visibility needs and aging driver population trends, some transportation agencies have begun to use longitudinal pavement markings that are wider than the 4-inch minimum for standard centerline, edge line, or lane line applications. This report describes a project with two primary activities. The first activity was identifying the current use of wider markings among transportation agencies in the United States, Canada, and other countries. The second activity was a review of the technical literature related to wider markings, with a particular emphasis on previous studies of the costs and benefits of using wider markings. The following is a summary of the significant findings from the project.

CURRENT USE OF WIDER MARKINGS

- The figure below shows that, as of late summer 2001, 29 of the 50 state departments of transportation (DOTs) use wider markings to some degree for standard centerline, edge line, and/or lane line applications.

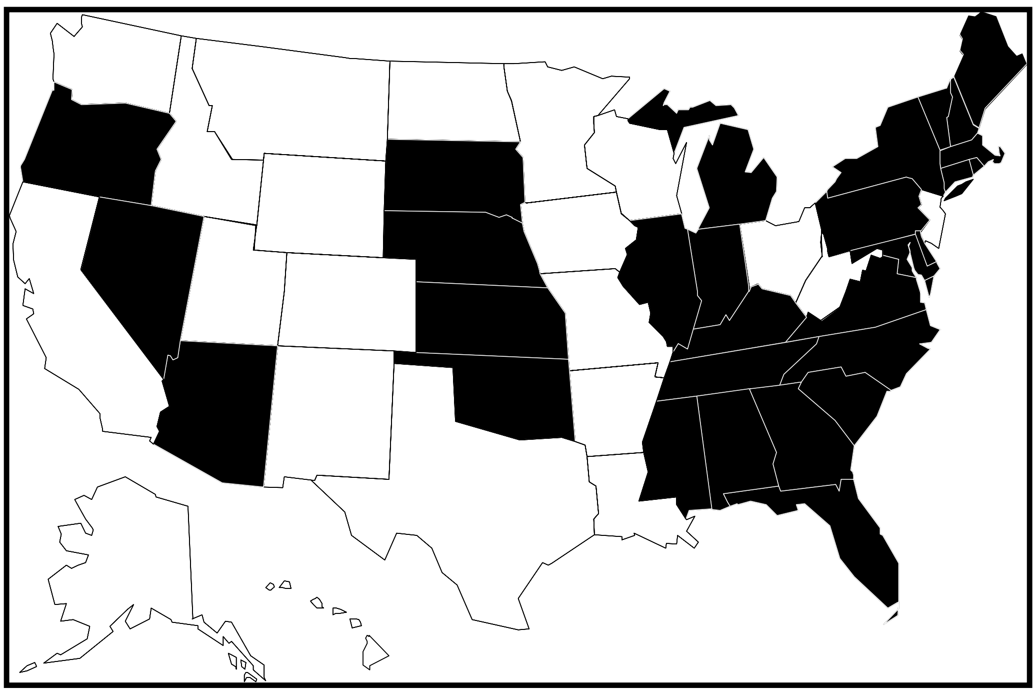

Figure S-1. Use of Wider Markings among State DOTs (black fill denotes use).

- The most widely cited reason for using wider markings is improved marking visibility (57 percent of respondents).
- The most common justification for implementing wider markings are pilot studies (32 percent of respondents), experience of other agencies (30 percent), and engineering judgment (27 percent).

- Most agencies (57 percent of respondents) have not measured the benefits of using wider markings.
- Most agencies using wider markings are satisfied with their use, and no agency indicated planned discontinuation of their use in the future.
- Some agencies that are not currently using wider markings are strongly considering their use.
- The survey findings indicate that the use of wider markings will continue to increase both in the total number of agencies using wider markings and the extent to which they are used in individual agencies.

BENEFITS AND DRAWBACKS OF USING WIDER MARKINGS

- Based on the technical literature and agency responses, wider markings provide the following benefits:
    - improved long-range detection under nighttime driving conditions (older drivers benefit the most),
    - improved stimulation of the peripheral vision,
    - improved lane positioning and other driver performance measures, and
    - improved driver comfort.
- Mostly due to increased amounts of materials used, wider markings often cost more to implement than 4-inch markings. Increased cost was the only drawback cited by agencies and is dependent on marking width, contract size, materials used and striping procedure.

ROADWAYS WHERE WIDER MARKINGS MAY PROVIDE GREATEST BENEFITS

Based on the findings from the literature and survey of agency practice, wider markings would likely have the greatest benefit when used in the following situations:

- locations where a higher degree of lane or roadway definition is perceived as necessary to all drivers, including:
    - horizontal curves,
    - roadways with narrow shoulders or no shoulders, and
    - construction work zones;
- locations where low luminance contrast of markings is common; and
- locations where older drivers are prevalent and thus require added roadway visibility under all conditions.

CHAPTER 1
INTRODUCTION

Pavement markings are considered by many to be the most valuable and important means of communicating roadway information to the driver. Longitudinal pavement markings provide a continuous stream of information about the roadway that cannot be provided by signs or signals. The current standards defining the color, pattern, width, and use of longitudinal pavement markings in the United States have been essentially the same since the publication of the 1971 Manual of Uniform Traffic Control Devices (MUTCD) (*1,2,3,4*). Current and past versions of the MUTCD have specified the width of a "normal" longitudinal line for general centerline, edge line, or lane line applications to be 4 inches to 6 inches, with most transportation agencies historically using 4-inch lines as standard (*1,2,3,4,5,6*). A nearly identical specification is used in the current version of the Canadian MUTCD, as well (*7*). Many other countries, especially those in Europe, use wider markings as part of all-white pavement marking systems and have done so for many years. However, there is no single or universal all-white pavement marking system.

An increasing number of transportation agencies worldwide have begun to use wider-than-standard longitudinal pavement markings over the past two decades for purposes of enhancing roadway safety. Over the same time period, the use of wider markings within individual agencies has generally increased, as well. For purposes of this report, the term "wider markings" has been used to characterize longitudinal pavement markings (centerline, lane line, or edge line) that are greater than the minimum 4-inch standard as specified by the national MUTCD. (Note: This definition differs from that used in the national MUTCD to define a "wide line," which is a line that is at least twice the normal width [*3,4*].) The definition of wider markings used herein does not include transverse markings or longitudinal markings that have traditionally been applied at widths greater than 4 inches, including turn lanes, gore areas, bicycle lanes, and acceleration/deceleration lanes.

STANDARDS PERTAINING TO MARKING WIDTH

In the United States and Canada, the color, pattern (length of marking and length of gap), and width of longitudinal pavement markings are the primary measures of conveying necessary delineation information to motorists. The use and function of color (white or yellow) and pattern (solid, broken, or dotted) are clearly defined in the MUTCD for pavement markings. However, the use and function of marking width is not so clearly defined. While it is clear that longitudinal markings must be at least 4 inches in width, the U.S. national MUTCD makes no mention about the use of longitudinal marking width for conveyance of a specific delineation message other than as follows in section 3A.06, Item C (*4*) (a similar statement exists in the Canadian MUTCD):

"Width of the line indicates the degree of emphasis."

This statement first appeared in the 1971 national MUTCD and has since remained unchanged. Previous versions of the national MUTCD contain similar, although more directive, language for wider marking use. For example, the 1948 and 1961 versions of the MUTCD state (*5,6*):

> *"Longitudinal pavement lines shall be from 4 to 6 inches wide. The most common width is 4 inches, but 6-inch lines, favored by a number of highway departments, provide added visibility."*

In these versions, the MUTCD provides more direction to *why* an agency should choose to implement wider markings. However, based on the language of current and past MUTCDs, it is apparent that the use of wider longitudinal pavement markings in North America is - and always has been - left to the discretion of the controlling transportation agency.

Wider markings are used extensively worldwide, especially in Europe where wider markings (in some cases up to 12 inches as a standard application) are often used as part of an all-white pavement marking system. In an all-white system, yellow is not used to convey the message of opposing traffic. Therefore, other marking attributes such as pattern, width, and spacing are used in an all-white system to convey this message. However, the use of these attributes varies from country to country.

DRIVER DELINEATION NEEDS

In a general sense, the ability of a driver to safely operate a vehicle is based on the driver's perception of a situation, level of alertness, the amount of information available, and the driver's information assimilation capabilities (*8*). Although the transportation profession can do little to control a driver's level of alertness or information-processing capabilities, the presentation of information can be designed for in the form of traffic control devices - including pavement markings. To be effective, pavement markings must:

- present the appropriate visual clues far enough in advance of a given situation to allow for suitable reaction time to occur, and
- be visible in the periphery to aid in moment-to-moment lane navigation.

This is especially true at night when the visibility of the roadway and surrounding features drops dramatically, causing motorists to rely heavily on pavement marking retroreflection for delineation cues. While many factors are involved in long-distance and peripheral detection of markings, the retroreflectivity and width of markings are two variables that can be engineered by transportation agencies and have been shown in the literature to influence marking visibility.

Many pavement marking visibility efforts, especially those occurring in the past decade, have taken older drivers into consideration. While locations exist that require improved delineation visibility for all drivers, age-related visual deficiencies amplify this requirement for older drivers. Compared to younger drivers, older drivers need greater levels of illumination and luminance contrast to see objects clearly, especially at night. Cognitive capabilities, which include attention and information processing, also decline with age. Visual and cognitive deficiencies often result in drivers having shorter preview times, longer perception-reaction times, and increased driver workload. Therefore, improving the visibility of pavement markings through brighter and wider markings offsets these deficiencies by providing the older driver with a longer preview distance and better stimulation of the peripheral vision.

The literature review produced a number of documents related to the use of wider markings as a countermeasure to driving deficiencies associated with age. The Federal Highway Administration (FHWA) *Roadway Delineation Practices Handbook* recommends that older drivers be provided with more redundant and brighter forms of delineation, including 8-inch edge lines and improved marking retroreflectivity (*8*). One of the definitive documents of the past decade concerning older driver issues, TRB Special Report 218, *Transportation in an Aging Society*, makes suggestions about the use of wider markings for older driver enhancement, including replacing 4-inch edge lines with 8-inch edge lines on two-lane rural roadways (*9*). Although no mention is given to the specific basis for such a recommendation, the author does point out that while available evidence is not sufficiently precise to quantify the safety gains that older drivers can expect from enhanced delineation, all drivers will derive some benefit from improved delineation. Many of the recommendations from this document were supported by the FHWA and led to the development of the "Action Plan for Older Drivers" in 1989 and later the "Improved Highway Travel for an Aging Population" program that involved piloting roadway safety improvements for older drivers in certain states (*10*).

STUDY OBJECTIVES

The overall goal of this report is to identify the current agency use of wider markings in the United States, Canada, and worldwide and combine it with both published and unpublished literature to provide a comprehensive analysis of the use of wider markings and the benefits that they provide. The objectives of the research included the following:

1. Determine *who* is using wider markings.
2. Determine *what* lines are wider within each agency (e.g., centerline, edge line, and/or lane line).
3. Determine *where* the wider lines are being used within each agency (e.g., all routes, hazardous locations, etc.).
4. Determine *why* agencies are using wider markings.
5. Determine appropriate evaluation methods for agencies to use for consideration of wider vs. standard markings.
6. Determine the benefits that wider markings provide over standard-width markings.
7. Provide recommendations about the use of wider markings.
8. Provide suggestions for future research.

The research objectives were accomplished through three primary activities: a comprehensive literature review, a survey of U.S. and Canadian roadway agencies, and a survey of international roadway agencies. The literature review focused on all aspects of wider markings, but was particularly concentrated on literature that evaluated their effectiveness as a roadway safety improvement, whether directly (e.g., crashes) or indirectly (e.g., driver performance measures, visibility, and driver surveys). While the literature review was useful for determining the relationship of marking width to roadway safety and other benefits associated with wider markings, the comprehensive survey of roadway agencies in North America and abroad allowed for determination of the extent of wider marking usage, reasons for their use, and satisfaction.

This report is organized to include an assessment of the extent of wider marking usage in the U.S., Canada, and worldwide; available evaluation methods; benefits that wider markings provide; and basis for their implementation as reported by agency personnel and research publications. The researchers have also developed conclusions and recommendations regarding the use of wider pavement markings by transportation agencies and recommendations for future research.

CHAPTER 2
RESULTS OF U.S./CANADA SURVEY

While the origin of wider marking use in North America is unknown, it does appear that its use is on the rise, both in the number of agencies that are using them and in their use within agencies. Researchers found no prior comprehensive nationwide survey of wider marking usage among state departments of transportation (DOTs) in the literature. Previous editions of the MUTCD suggest that they may have been used since the early days of pavement delineation (*5*). Nonetheless, very little baseline data on historical usage of wider markings exists.

In the spring of 2001, a survey was administered to senior traffic engineers at each of the 50 U.S. state DOTs, Canadian provincial DOTs, and tollroad agencies to determine the current use of wider pavement markings in the U.S. and Canada. The survey was administered as a combined effort between Texas Transportation Institute (TTI) researchers and researchers at the University of Iowa Operator Performance Laboratory and included questions pertaining to both wider and brighter pavement markings. This survey was initially administered over the Internet and was followed up with telephone interviews of agency personnel. Design of the survey questions was based in general on the findings from the literature review, and answer categories were almost exclusively fill-in-the-blank. Responses were received from all 50 state DOTs, 2 U.S. cities, 7 tollroad authorities, and 6 Canadian provinces. A discussion of the agency responses can be found in the following paragraphs. Full agency responses can be found in Appendix B. The survey instrument can be found in Appendix A. The main objectives of the survey were to:

- determine the current use of wider pavement markings among agencies, including the line widths and types where they are used and the extent of their use within an agency;
- determine the reasons for using the wider markings and the basis for their implementation; and
- determine the benefits of using the wider markings.

EXTENT OF WIDER MARKING USE

Based on survey responses, 29 of the 50 state DOTs (58 percent) are currently using wider markings to some degree for centerline, lane line, or edge line applications (Figure 1). This excludes states that only use wider markings as part of an innovative pavement marking device, such as profiled or contrast markings, because these markings are often procured for characteristics other than increased width. The most significant finding from the survey is that wider marking use is concentrated in states east of the Mississippi River, with all but four of those 26 states (85 percent) using wider markings. Of the states west of the Mississippi, only seven of the 24 states (29 percent) use wider markings. Researchers could draw no definite conclusions to why this pattern exists. One plausible explanation is that wider markings were first used extensively in the early 1980s by transportation agencies in the Atlantic Coast region. Over time, neighboring jurisdictions began using wider markings, citing reasons such as providing consistency across jurisdictional boundaries and the success that neighboring agencies had found. As this process continued, the use of wider markings spread westward from the Atlantic Coast. This explanation is based on comments made by many of the responding agencies.

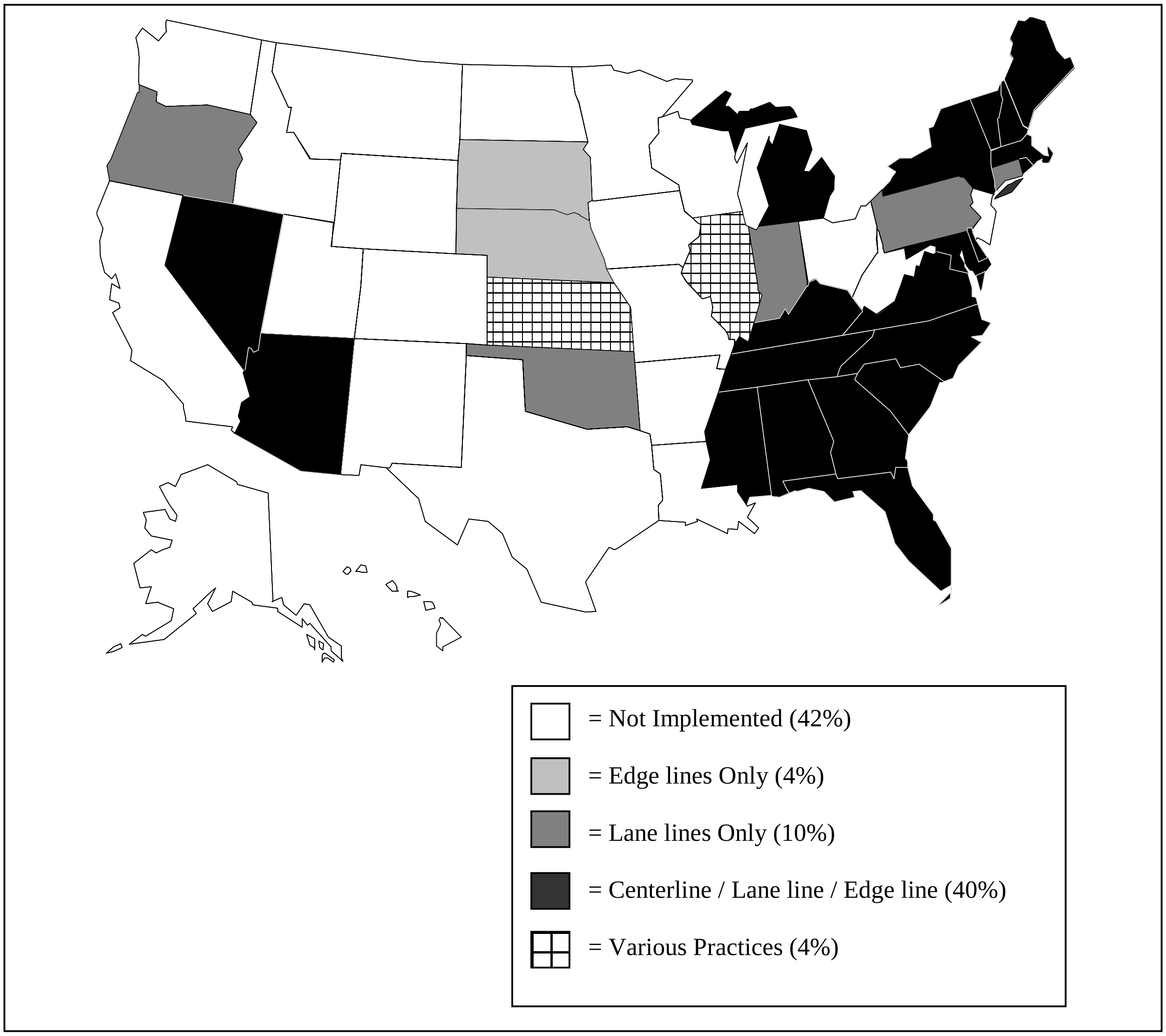

Figure 1. Line Types for Which Wider Markings are Used in State DOTs.

All seven of the responding tollroad authorities use 6-inch markings for lane line applications on all routes, with five of the seven using wider markings for edge line applications, as well. The consensus comment among the tollroad agencies was that because users pay a significant up-front cost for using their roadways, they demand and deserve an increased level of quality from the pavement markings. Of the six Canadian provinces that responded to the survey, only Ontario uses wider markings and only on a limited basis.

The common widths of wider markings used by state DOTs are shown in Figure 2. As expected, the actual widths of the wider markings vary from agency to agency, although 6 inches is the most common, especially east of the Appalachian Mountains. Eight-inch markings are the widest typical application reported, although the Maryland DOT reported recent experimentation with 10-inch edge lines on two sections of two-lane rural highway.

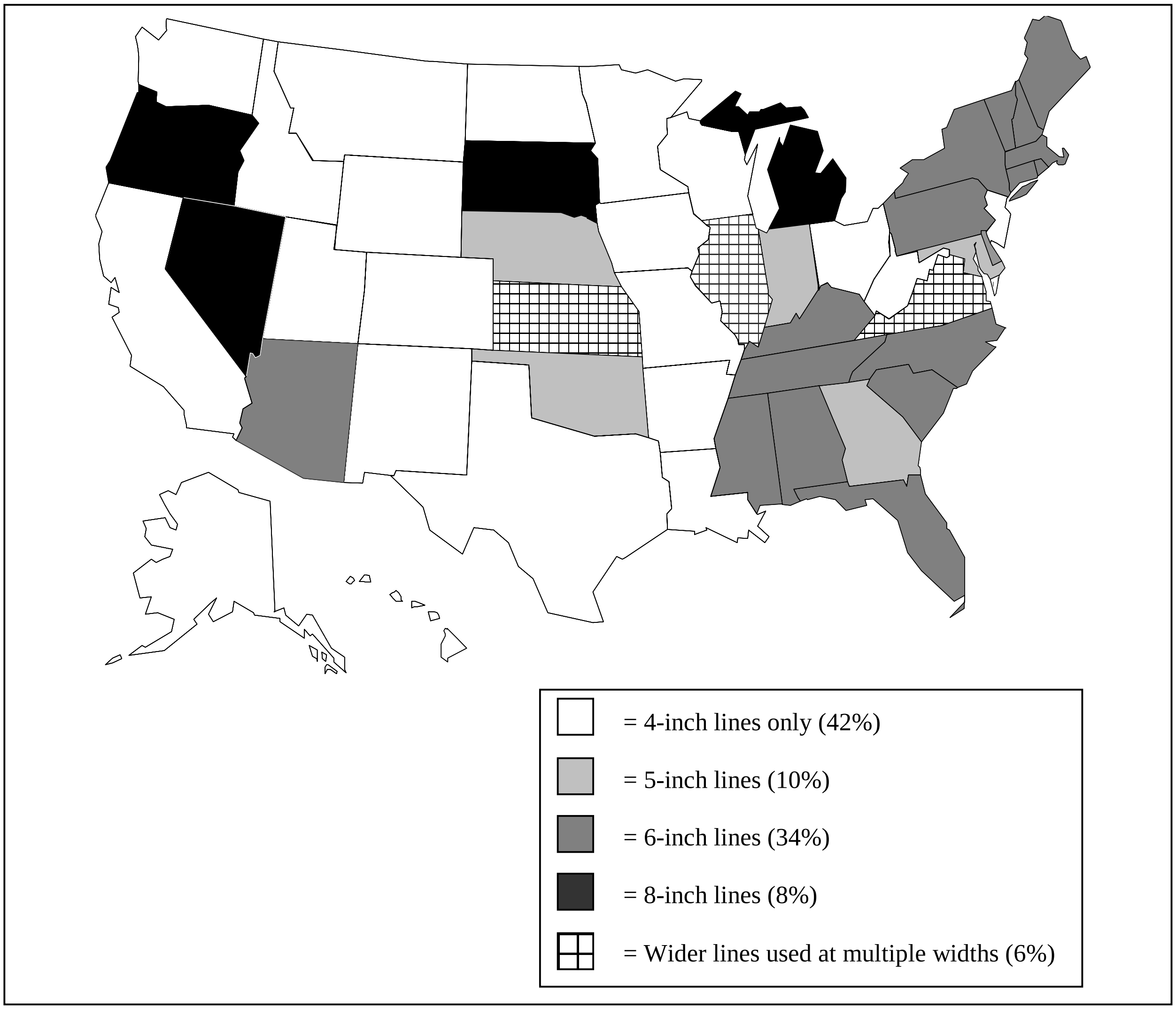

Figure 2. Line Width Usage by State DOT.

The survey responses show that the levels of implementation vary from agency to agency. There are five general implementation categories for wider marking implementation, which are as follows (in order from least extensive to most extensive in percentage of miles striped):

- not implemented,
- spot locations only,
- all routes of a certain classification,
- all routes of a certain classification and elsewhere at spot locations, and
- all routes statewide.

Figure 3 presents the breakdown of use by state DOTs. Of those agencies that use wider markings, the least extensive form of use is spot implementation, usually at hazardous locations or for pilot studies. As would be expected, the definition of hazardous location varies from agency to agency, but for the most part is either based on crash histories (usually run-off-road (ROR)), roadway geometry (e.g., curves or hills), roadway cross section (e.g., no shoulders), or in a major construction work zone. The most common use of wider markings among state DOTs is to use them on all routes of a certain roadway classification, most often full access-controlled highways, as part of a statewide policy. The highest level of implementation is wider marking use on all routes statewide, which is currently the policy of six state DOTs (Maryland, Florida, Mississippi, Alabama, Georgia, and Nebraska).

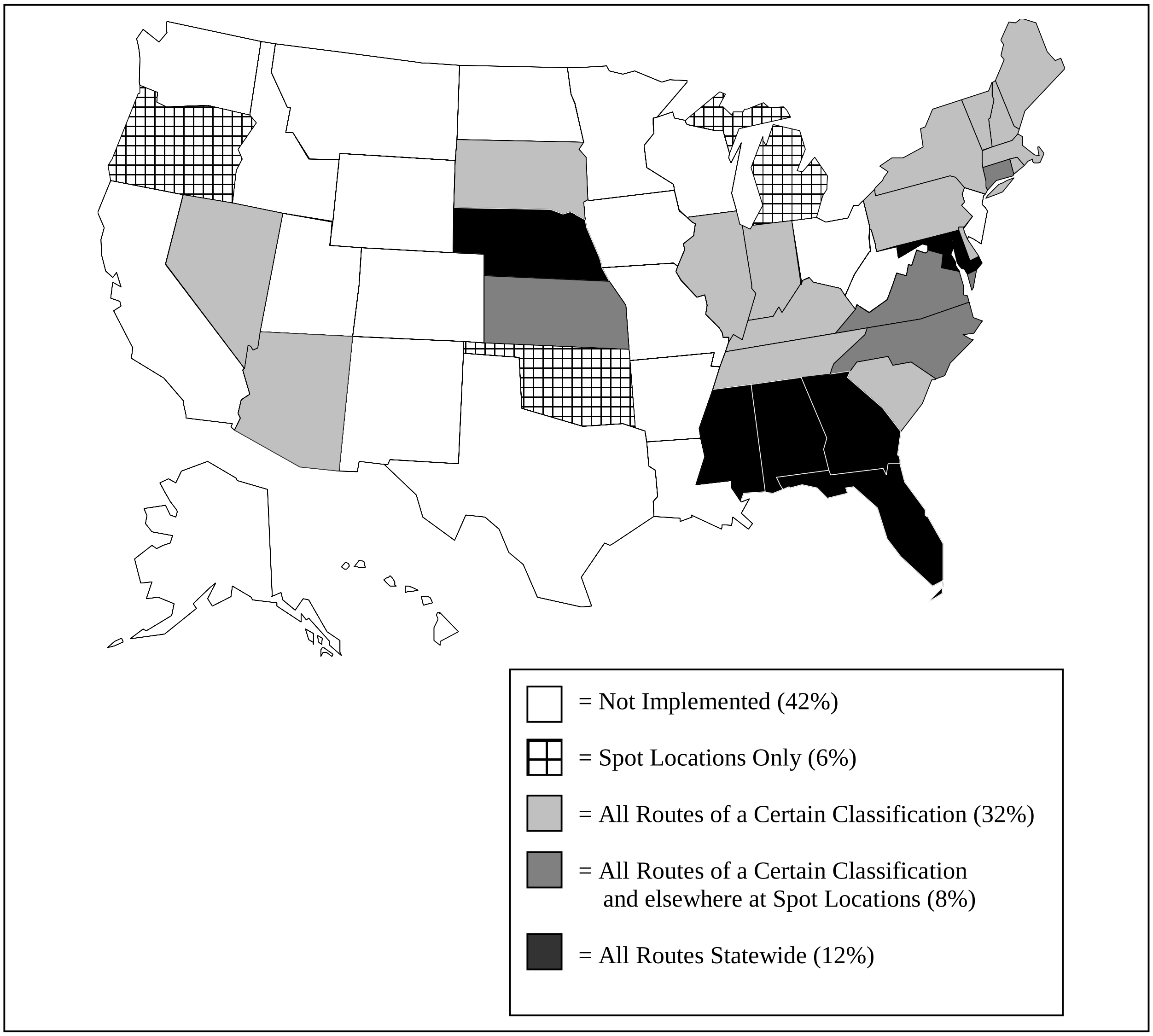

Figure 3. Roadways Where Wider Markings are Used within State DOTs.

REASONS FOR USING AND BASIS FOR IMPLEMENTATION

It appears that both the total number of agencies using wider markings and within-agency use has increased steadily in the U.S. since 1990 and continues to increase, much of it stemming from research findings of the past decade and the spiraling effect described previously. Many agency personnel stated that the desire to improve visibility for all drivers and in particular older drivers has prompted them to implement wider markings (Table 1). Visibility literature will be discussed later in this report. Some of the older driver references most often cited by transportation agencies include *TRB Special Report 218, FHWA Roadway Delineation Practices Handbook*, and the *Older Driver Highway Design Handbook* (*8,9,11*). Each suggests that wider markings provide visibility benefits to older drivers beyond 4-inch markings of the same retroreflectivity.

Table 1. Reasons for Using Wider Markings (U.S./Canadian Agencies).

Reasons for Using Wider Markings (Percent of Respondents)	
Visibility Improvement	57%
Older Driver Countermeasure	19%
Crash Reduction	14%
Driver Comfort/Aesthetics	8%
Provide Consistency with Nearby Agencies	5%
Driver Fatigue Countermeasure	3%
Service Life Improvement	3%
No Response/Unknown	16%

Note: Many agencies gave multiple responses.

While it is useful to identify the reasons that agencies use wider markings, the responses do not necessarily give an indication of the basis for implementation. Table 2 displays the agency responses as to the basis for implementation of the wider markings.

Table 2. Basis for Implementation (U.S./Canadian Agencies).

Basis for Implementation (Percent of Respondents)	
Results from Pilot Study	32%
Experience/Satisfaction of Other Agencies or to Provide Consistency	30%
Engineering Judgment	27%
Driver Surveys/Comments	8%
Literature Review	8%
Crash Reductions	3%
Service Life Improvements	3%
No Response/Unknown	24%

Note: Many agencies gave multiple responses.

Table 2 shows that agencies base the decision to implement wider markings on a broad range of factors. However, few indicated that documentation of the implementation process was available within their agency. Basis for implementation is overwhelmingly weighed toward subjective measures, while traditional objective measures, such as benefit/cost, crash, or service life analyses were uncommon responses. This report will describe later that cost-quantifiable data associated with wider pavement markings are not easily obtained, nor were conclusive data of this type found in the literature.

One of the best-known wider markings implementation programs in the U.S. took place in the Florida DOT in the early 1990s and was largely based on meeting the needs of older drivers. What first started as a part of the FHWA's "Older Driver Pilot Program" gradually developed into Florida's "Elder Roadway User Program" (*10*). This program included systemwide upgrades to many facets of roadway and traffic control device design and application to accommodate the needs of older drivers, including 6-inch pavement markings. Many other agencies began using wider markings based at least in part on Florida's experience or the FHWA's "Older Driver Pilot Program" as a whole.

Another high-profile implementation program took place in the Washington D.C. area in the early 1990s. Safety problems on the Capitol Beltway prompted the formation of an emergency task force to determine effective countermeasures. The task force recommended implementation of 6-inch edge lines and lane lines on the Beltway. As a result, 6-inch markings were implemented on the Beltway in 1993. This implementation program was provided with extensive media coverage and was met with an overwhelmingly favorable public response (*telephone conversations with current and former Virginia Department of Transportation personnel*).

OBSERVED BENEFITS

The benefits associated with the use of wider markings are of particular interest to transportation agencies that are considering their implementation. Quantifying the benefits associated with wider markings, especially those used in cost-effectiveness evaluations, has proven to be a difficult task for agencies and researchers alike. Furthermore, published and unpublished crash studies performed by transportation agencies have primarily shown inconclusive evidence. However, crash reductions have been observed under certain roadway situations, which will be discussed in further detail later in the report. Table 3 displays the benefits associated with wider marking use and evidence of crash reductions as reported by transportation agencies.

Table 3 shows that most of the benefits measured by agencies are subjective in nature if any are measured at all. Conclusive crash data are not available within the agencies. However, appropriate measures of effectiveness and benefits associated with wider markings have been identified based on discussion with transportation personnel and critical review of the literature and are described in detail in Chapter 4.

Table 3. Observed Benefits of Wider Markings (U.S./Canadian Agencies).

Observed Benefits (Percent of Respondents)		Observance of Crash Reductions (Percent of Respondents)	
None Measured/Unknown/No Response	57%	Analysis Has Not Been Performed	65%
Favorable Public Response	30%	No Significant Findings	22%
Improved Visibility (mostly subjective)	30%	Significant Crash Reduction	3%
Improved Driver Comfort/Aesthetics	5%	No Response	10%
Crash Reduction	3%		
Improved Service Life	3%		

Note: Many agencies gave multiple responses.

SATISFACTION AND DRAWBACKS

The survey produced evidence that personnel from most agencies using wider markings are satisfied and will continue with their use. Common reasons cited for high levels of satisfaction centered on visibility improvements (usually subjective) and positive feedback from drivers. Many agencies are also increasing levels of wider marking implementation. Only three agencies (Maryland DOT, Indiana DOT, and Nebraska DOT) indicated that they have actually reduced wider marking use as a standard application in the past, either by reducing the widths or reducing the number of locations where wider markings are striped, due to budget restrictions or application procedures. No agency currently using wider markings indicated discontinuation of their use in the future in favor of 4-inch markings.

The main drawback cited to the use of wider markings is the increased cost over 4-inch markings, the magnitude of which depends on the marking width, contract size, materials used and striping procedure. Recent cost estimates by the Arizona DOT predicted a 38 percent increase in contracted cost for 6-inch thermoplastic markings compared to 4-inch markings (*unpublished internal memo from Arizona DOT*). A recent pilot study of 5-inch lane lines by the Oklahoma DOT showed a 20 percent increase in striping costs over 4-inch (*telephone conversation with Oklahoma DOT personnel*). Implementation of 8-inch lines by the Nevada DOT has, over time, resulted in consistent unit striping cost increases of approximately 50 percent (*telephone conversation with Nevada DOT personnel*).

Of all agencies that do not currently use wider markings, the most common reason for not using them is that there is little or no conclusive evidence that wider markings reduce crashes, and therefore the increased cost cannot be justified. Others commented that while they would like to implement wider markings, budget restrictions currently do not allow for their use. However, equally as common of a response was that their use will be considered if conclusive evidence of their effectiveness as a highway safety treatment is established.

CHAPTER 3
INTERNATIONAL USE OF WIDER PAVEMENT MARKINGS

Longitudinal markings wider than 4 inches have been used internationally as standard application for many years. In many countries - especially in Europe - wider markings are often used as part of all-white pavement marking systems. Because marking width is often used to convey a different message in all-white marking systems than in the yellow-white systems common to North America, the intent of the review of international practice was not so much to determine the actual widths of markings, but rather to determine if agencies have increased marking widths, reasons for increasing the widths, and significant findings as a result of the increases. Awareness of pavement marking quality and how it relates to driver needs has been amplified in Europe as of late after recent completion of a continent-wide comprehensive research initiative, entitled *COST 331, Requirements for Horizontal Road Marking (12).*

EUROPEAN EVALUATION

One of the most comprehensive pavement marking studies of late was performed in the latter half of the 1990s by the European Cooperation in the Field of Scientific and Technical Research (COST). The researchers involved with COST 331 sought as their goal the establishment of an up-to-date scientific method to determine the optimum pavement marking design to ensure that markings are visible during the day and night and under all weather conditions, while taking into consideration drivers' visual needs. The researchers succeeded in development of a computer software visibility model to aid practitioners in the design of pavement markings. The model was based largely on foveal target detection research by W. Adrian (*13*). Assuming all else is constant, the model suggests that the "visibility level" of a pavement marking is largely a function of the luminance contrast between the marking and the roadway surface and the size of the pavement marking, suggesting that wider markings do provide a benefit to target detectibility. At least one country (Sweden) uses this computer model to aid in the design of pavement marking retroreflectivity and width.

Included in the COST 331 research was an extensive surrogate measures evaluation (*12*). In this evaluation, researchers recorded surrogate measures for subjects driving an unobtrusive instrumented vehicle at three different field locations. Four different marking width/pattern/retroreflectivity combinations were compared in this experiment. Results showed that 30-cm (12-inch) edge lines provided for the most central positioning of vehicles for tangent sections and right and left curve sections when compared to roadway sections with 10-cm (4-inch) edge lines or no edge lines. An interesting finding from this study was that no significant speed increases occurred as a result of increases in marking width or retroreflectivity, making the case that drivers do not negate the increases in preview distance by consequently increasing their speed.

WORLDWIDE MARKING WIDTHS

In spring and summer of 2001, a survey was administered via e-mail to prominent traffic engineers and researchers in 17 countries worldwide. The purpose of this survey was to determine if marking widths have been increased in the recent past and, if so, for what reasons. This survey was far less comprehensive than the U.S./Canada, survey due to the differing pavement marking practices and standards that exist internationally. The survey questions were exclusively fill-in-the-blank. The international survey instrument can be found in Appendix C. A summary of each agency response can be found in tabular format in Appendix D. Unfortunately, despite repeated attempts, responses from only nine nations were obtained. Presented in Table 4 are the common pavement marking widths on access-controlled highways for a number of countries worldwide. Information in Table 4 has been taken from the COST 331 report and the international survey. Information from the survey and the COST 331 report shows that countries using all-white marking systems use a variety of widths and patterns to convey delineation information, but these parameters are not used consistently or uniformly between nations.

Analysis of Table 4 makes it very clear that internationally, at least on high-type roadways, markings wider than 4 inches (10 cm) are used extensively, especially for edge lines, likely due to the improved visual signal that they provide. Five of the nine nations have increased the widths of certain marking types in the recent past. The reasons cited for increasing marking width were centered exclusively on the visual benefits provided to the motorist. Mexico's national roadway agency reported that improved striping and signing, combined, have produced a decrease in crashes on implemented highways. It also appears that as a result of COST 331, some European nations are placing increased emphasis on design of pavement markings (retroreflectivity, width, and pattern) for a given facility based on parameters such as roadway speed, human factors, pavement type, etc.

Table 4. International Pavement Marking Widths on Access-Controlled Highways.

Country	*Standard Width of Markings on Access-Controlled Highways (cm)*		*Have Widths Been Increased?*	*For What Reason?*
	Edge lines	*Lane lines*		
Belgium	30	20	NR	NR
Denmark	30	15	**NO**	**Focus has been on improvements in retro. through the use of thermo and beads**
Finland	20	10	NR	NR
France	22.5	10	NR	NR
Germany	30	15	**NO**	**Crashes cannot be accurately predicted**
Greece	12	12	NR	NR
Hungary	20	12	**NO**	**Economic reasons**
Iceland	10	10	**YES, pilot project with 20-cm edge line**	**To improve visibility**
Ireland	15	10	**YES, 15-cm edge lines are now used on national highways and centerlines on undivided routes**	**To improve visibility – “more forceful” in defining edge of road**
Italy	15	15	NR	NR
Mexico	15	15	**YES, 15-cm is now used for all lines on major highways and at other locations with poor visibility**	**The need for improved visibility on high speed roads**
Netherlands	15	10	**NO**	**Experimenting with different edge line patterns, but not widths**
Norway	20	15	NR	NR
Portugal	20	15	NR	NR
Slovenia	20	15	NR	NR
South Africa	15	10	**YES, 20-cm edge lines are now used where ROR crash risk is present; 20-cm centerline used on two-way undivided roadways**	**Improved visibility**
Spain	20	10	NR	NR
Sweden	30	15	**YES, 15-cm centerlines/lane lines are now used on major highways with average daily traffic (ADT) over 4000; COST 331 model is now being used to design markings**	**To improve visual guidance at night on major highways**
Switzerland	20	15	NR	NR
United Kingdom	20	10	NR	NR

Note: 1 cm = 0.394 inches
NR = No Response.

CHAPTER 4
WIDER MARKING EVALUATION METHODS

While the presence of longitudinal pavement markings provides crash reductions vs. no markings at all (*14,15,16,17*), evidence is inconclusive whether or not *wider* pavement markings are an effective means to improve highway safety. Whether or not wider markings are considered effective is often a function of the evaluation methodology used, which will be further described herein. Included first is a description of the crashes that are typically recognized as delineation-related, and thus are often considered the most likely to be affected by changes in marking width.

DELINEATION-RELATED CRASHES

Multiple sources have identified certain types of highway crashes as being at least partially related to pavement delineation under certain circumstances. The crash types that are most commonly correlated to pavement delineation are run-off-road and opposite-direction crashes. Some studies have suggested that the use of wider markings may play a role in the reduction of these crash types under certain conditions (*18,19,20*). Run-off-road and opposite-direction crashes are generally over represented on our nation's highways, especially on horizontal curves and at night, when fatal crashes are four times more likely to occur. In addition, due to visual and cognitive deficiencies, older and impaired drivers are especially susceptible to these types of crashes. Therefore, the crash types that are most likely related to marking width are run-off-road and opposite-direction crashes that:

- occur at night,
- occur on curves, and
- involve drivers with reduced visual or cognitive capabilities (e.g., older drivers or impaired drivers).

While these types of crashes may be delineation-related, the ability to directly measure the effect that using wider markings have on the frequency of their occurrence is not an easy task.

COST-ASSIGNABLE MEASURES OF EFFECTIVENESS

Cost-effectiveness (or benefit/cost) analyses are a standard measure that transportation agencies use to compare highway safety improvements and to make decisions about their use. Pavement markings have traditionally been viewed by most transportation agencies as a very low cost means of improving highway safety. A 1991 study by T.R. Miller showed that on average, pavement striping yields a 60:1 benefit/cost ratio over no striping at all with average annual benefits estimated at $19,226 per line-mile (*15*).

To perform any kind of cost-effectiveness analysis, actual dollar values for both the costs and benefits are necessary. In the case of delineation-related evaluations, a minimum of three types of information are needed: striping costs, service life data, and delineation-related accident costs (*21*). Striping costs vary considerably by materials used, state, year of installation, whether the work is contracted out or performed by the agency, and size of contract. Recent estimates suggest that the cost increase for striping 5 or 6-inch vs. 4-inch markings is approximately 20-40 percent (*data provided by Oklahoma and Arizona DOT personnel*). In the late 1980's Hughes, et al., approximated the cost increase for 8-inch vs. 4-inch painted edge lines to be on the order of 50-75 percent based on contract striping cost data supplied by the Massachusetts and Alabama DOTs (*20*). Eight-inch striping in Nevada has produced consistent 50 percent increases in contracted costs per unit length over 4-inch (*data provided by Nevada DOT personnel*). Such increases in cost are due largely to the increased material quantities used for the wider lines. Consequently, for a wider pavement marking to be cost-effective relative to a standard 4-inch pavement marking, the wider marking must be shown to reduce crashes and/or increase the length of the striping cycle by an amount equivalent to the expected increase in costs incurred by striping the wider lines (*21*).

A benefit/cost analysis performed by Hughes, et al. in the early 1980s determined that an annual reduction of only eight edge line-related crashes for every 1000 miles striped with 8-inch edge lines would allow for the wider lines to be cost-effective (*21*). Therefore, traditional measures of effectiveness have centered on crash and service life evaluations, mainly because the results can be translated into dollar values and can be directly compared to increases in striping costs.

Service Life Evaluations

Service life of wider markings compared to the standard 4-inch markings is a dollar-assignable measure that has been investigated in a small number of studies. The general hypothesis is that because wider markings cover a larger surface area, they will be able to withstand greater material loss than a 4-inch edge line and, hence, have a longer service life (*21*). Improvements in marking durability would enter into cost-effectiveness analyses only if they lead to an increase in the restripe cycle time. In addition, increases in restripe cycle time may also be considered a safety benefit because of the decreased striping-crew exposure on a given roadway. However, evidence is inconclusive as to whether or not service life improvements would be expected as a result of wider markings.

Researchers conducted service life comparisons for 4-inch vs. 8-inch edge lines on two-lane roads at 36 locations across 5 states in the 1989 FHWA study by Hughes, et al. (*20*). The markings were rated based on three criteria: appearance, durability, and night visibility. Although some of the locations showed slightly higher ratings for the 8-inch compared to the 4-inch markings, no clear difference in service life between the two edge line widths was found. The authors did point out, however, that the small sample size might have played a role in the inconclusiveness of the results. On the other hand, the New York DOT conducted its own investigation into the effect of increasing edge line widths on marking service life (*22*). It was concluded that wider lines can withstand more material loss resulting from snowplow abrasion, cracking, and chipping and still provide good visibility when compared to a 4-inch line.

Crash Evaluations

Traditional evaluation methods have been heavily focused on measuring crash reductions resulting from wider markings use. Crash evaluations have historically been the preferred method of evaluation because a dollar value can be assigned to the results if differences are found between the before and after periods and therefore can be used in benefit/cost analyses. Ten state DOTs stated in the survey that they have performed or taken part in crash studies, both published and unpublished, and have generally found inconclusive results.

Separate studies by Hall and Cottrell performed for the New Mexico and Virginia DOTs, respectively, found that 8-inch edge lines did not produce statistically significant run-off-road crash reductions compared to standard 4-inch edge lines (*18,19*). Hughes, et al. concluded that based on available crash data from Ohio, Maine and Texas, 8-inch edge lines were not found to reduce crash frequencies relative to 4-inch edge lines on two-lane rural roadways with between 5,000 and 10,000 vehicles per day (*20*). A small crash study was recently performed by the Maryland DOT at two hazardous sites where 10-inch edge lines were applied as an experimental crash countermeasure. No conclusive results were found (*reported by Maryland DOT and unpublished internal documents*). A before and after crash study comparing 4-inch vs. 8-inch edge lines was performed by the Kansas DOT in the early 1990s on a piloted section of two-lane highway without shoulders. No appreciable difference in crashes was observed between the before and after periods (*reported by Kansas DOT and unpublished internal documents*). An internal crash study in the late 1970s by the Maine DOT showed that 6 and 8-inch edge lines produced no significant ROR crash reductions when compared to 4-inch edge lines (*reported by Maine DOT*). The Texas DOT found similar results in an internal before-after study performed in the mid-1980s. The analysis compared run-off-road (ROR) crashes on over 200 miles of rural highways striped with 8-inch edge lines to those crashes on control sections striped with 4-inch lines. No significant crash reduction was found (*unpublished internal documents from Texas DOT*). Similar inconclusive results from crash analyses were reported by the North Carolina and Oklahoma DOTs (*reported by North Carolina DOT and Oklahoma DOT*).

Some crash studies, on the other hand, have produced data to support the usefulness of wider markings for reducing certain types of crashes in certain roadway situations. In the 1989 FHWA study conducted by Hughes, et al., researchers found that for 24-foot-wide rural roadways with less than six-foot shoulders and average daily traffic (ADT) volumes between 2,000 and 5,000, those roadways striped with 8-inch edge lines experienced a relative decrease in total crash rate, total crash frequency and injury/fatal crash rate compared to similar sections striped with 4-inch edge lines (*20*). These findings were based on information provided by the Alabama DOT for nearly 300 miles of two-lane rural highways. Crash data from South Dakota on highways of the same class showed similar results. Based on their findings, the researchers recommended that 8-inch edge lines appear to be appropriate and cost-effective on roadways with the following conditions (*20*):

- ADT volumes between 2,000 and 5,000 vpd,
- pavement widths equal to 24-feet with unpaved shoulders, and
- frequent rainfall.

The authors also recommended that wider edge lines might be more appropriate as a safety improvement when applied at spot locations, such as isolated horizontal curves and approaches to narrow bridges (*20*).

The Montana DOT implemented wider markings as part of an older driver corridor upgrade in the early 1990s, which also included sign and geometric upgrades and an educational component. Crashes were monitored for three years in both the before and after periods. A detailed crash analysis found that crash rates along the corridor were reduced 18 percent in the after period for older drivers and 8.3 percent for all drivers (*23*). Please note that part of the crash reduction may be attributable to the non-pavement marking improvements that were made. A study in Morris County, New Jersey found that for roadways with 8-inch-wide edge lines, fatal and injury crashes on dry pavements declined by 16.1 percent compared to a decline of 8.2 percent on other county roads in New Jersey without 8-inch edge lines (*24*,*25*). However, the statistical validity of this study is questionable. It should be noted that the literature review produced no studies investigating the effect of wider centerlines on opposite-direction crashes.

Although crash data provide a direct measure of the safety benefits provided by a treatment, due to the random and infrequent nature of crash occurrences, crash studies require a considerable devotion of time, resources, and site control by a transportation agency to produce meaningful results, which often cannot be met by the agency. This is especially true for studies involving relatively small changes in effect size, such as those involving wider markings because in general, the smaller the change to be detected, the larger the sample size needed to detect statistical significance (*20*). Due to the relatively small change in the independent variable (marking width) in the before and after periods, expected differences in crash rates between the two periods would be relatively small. The fact that small changes in effect size are being measured makes wider markings crash studies especially vulnerable to common statistical errors both systematic (e.g., bias) and random (e.g., Type I and II errors) in nature.[1] For further commentary on the drawbacks and misconceptions associated with before-after safety studies, please refer to the ITE Manual of Transportation Engineering Studies and selected works by Ezra Hauer, Campbell and Stanley, and Simon Washington (*26*,*27*,*28*,*29*).

Conclusive evidence that wider markings reduce crashes is not available in the literature or in transportation agencies, although some positive findings have been found. This is primarily due to the difficulty of conducting before-and-after studies where the only change is the width of the marking. As a result, the cost-effectiveness of wider markings has not been well established. Recognizing, however, that conclusive crash data are not available and/or would be extremely difficult to obtain, transportation agencies and researchers alike have resorted to other methods of evaluation to serve as an indirect measure of improved highway safety.

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[1] Researchers must be wary of factors other than marking width that may influence crashes in the before and after periods. These include the obvious, such as changes in traffic volumes or construction, and the subtle, such as changes in retroreflectivity of the markings, presence/absence of retroreflective raised pavement markers, sign upgrades, roadside delineation upgrades and other road improvements.

INDIRECT MEASURES OF EFFECTIVENESS

The lack of conclusive cost-quantifiable research results has led many transportation agencies and researchers to turn to other means to evaluate the use of wider markings, acknowledging that improvements in such measures *imply* improvements to roadway safety. These types of evaluations include driver opinion surveys/comments, intermediate or surrogate measures (e.g., lane placement/encroachment), and visibility measures (e.g., end-detection distance). Unfortunately, because their direct relationship to crashes has not been established, these implied safety measures are not easily assigned a monetary value to reflect measured benefits.

Driver Opinions

Opinions of the driving public have been used by transportation agencies to evaluate wider pavement markings and, in some cases, are used to assist in policy decisions. These methods of evaluation do serve as a good indicator of customer service and driver comfort and oftentimes play a major role in an agency's opinion of wider markings. However, the subjective nature of this evaluation method limits its use in a quantitative sense.

In the survey of transportation agencies, many agency personnel commented that they have received favorable public response after wider marking implementation, although little documentation exists. Published public opinion surveys by the South Dakota DOT show that the driving public views pavement markings in general as a very important safety tool. A public opinion survey published by the SDDOT in 1997 shows that "keeping stripes visible" was the third-highest ranked attribute out of 21 for resource allocation (money and services) as rated by both 768 members of the driving public and 32 state legislators (*30*). Furthermore, the average respondent in this survey indicated that 9 percent of the total DOT resources should be spent on this attribute, a higher percentage than was recommended to be allocated for designing new highways, highway planning, and highway signs and traffic signals. A follow-up public opinion survey in 1999 showed that 81 percent of the 734 respondents felt that poor pavement markings would somewhat or very likely interfere with safe travel (*31*). While neither of these surveys directly examined the opinions of the public toward wider markings, it is clear that providing quality pavement markings is a high priority of the traveling public.

A.M. Ward reported on a driver survey in the mid-1980s that evaluated the effectiveness of 8-inch edge lines and roadside post delineators in enhancing safety for older drivers (*24*). Eighteen American Association of Retired Persons (AARP) instructors each drove a test course in both daylight and darkness and were then interviewed. The results indicated that 94 percent of the respondents said that 8-inch edge lines affect the way they drive, especially as an aid to staying on the road and in their lane. In addition, 93 percent of the respondents said that the combination of 8-inch edge lines and fully reflective delineator posts had a positive effect in providing more information about the roadway, leading them to feel safer and more secure. As a result, the AARP task force gave their endorsement to the use of tax dollars to install wider edge lines and fully reflective posts.

Research by Schnell and Ohme reported that drivers participating in a field detection distance evaluation generally judged wider markings as more favorable than 4-inch markings (*32*). Similar results were observed by Hostetter, et al. in simulator evaluations of 8-inch vs. 4-inch edge lines (*33*). However, the researchers in both cases found that perceived quality and brightness of markings did not correlate well with objective end-detection performance for markings of different widths.

Driver surveys have been shown to influence policy-making decisions. One of the more widely recognized cases was the implementation of 6-inch markings statewide by the Florida DOT. Implementation was based, in part, on older driver surveys conducted in Florida, which showed that older drivers preferred the wider markings. (*unpublished information obtained from Florida DOT*). Representatives from the North Carolina, Virginia, and Maryland DOTs also indicated that positive responses from driver surveys played a significant role in the decision to implement wider markings in their respective states (*unpublished information obtained from North Carolina DOT, Virginia DOT and Maryland DOT*).

Intermediate/Surrogate Measures

A number of studies examined the use of wider edge lines and their effect on surrogate measures for crashes, including lateral placement variance, mean lateral placement, centerline or edge line encroachment, weaving, etc. The reason for testing the effectiveness of these “intermediate” measures is that crashes are rare events, and consequently, improvements in such measures would ultimately correlate to a lower crash frequency. However, although intermediate measures provide a surrogate for the direct measurement of crashes, the inability to assign a monetary value to reflect any benefits remains a drawback to this type of analysis.

A closed-course study in the early 1980s showed improvements in vehicle positioning measures for an 8-inch edge line vs. a 4-inch edge line on curved roadways using alcohol-impaired vs. non impaired drivers. In this study, 16 male subjects in their early 20s drove on an isolated section of two-lane roadway in New Jersey between midnight and 3 a.m. Each subject drove the course twice, the first after consuming a placebo drink (0.0 percent blood alcohol content) and the second after consuming either a placebo drink or controlled alcohol dosage (0.05 or 0.08 percent blood alcohol content). Fewer centerline encroachments, more central positioning within the lane, and less variability in positioning among drivers were observed for the wider edge lines (6 and 8 inch) vs. the 4-inch edge lines. The authors concluded that the improved driving performance of the test subjects in the presence of wide edge lines indicates that strengthening the visual signal at the road edge may help partially compensate for visual impairments, although benefits are provided to all drivers (*34*).

A field surrogate measures study performed in Virginia found that while other driver performance measures were of no significance, mean lateral placement of vehicles was significantly more centered within the lane for an 8-inch-wide edge line vs. a 4-inch-wide edge line (*35*). Another field study in Massachusetts in the late 1980s showed that fewer lane departures were observed on curved highway segments with 8-inch edge lines when compared to 4-inch edge lines used in the control group (*20*). The authors commented that based on results, it appears that driver performance in traversing curves on roads with 8-inch edge lines is better than on roads with 4-inch edge lines. A recent simulator evaluation by McKnight, et al. found that increasing line width had a large positive effect on lane keeping at extremely low contrast ratios, similar to those encountered on wet roads (*36*). While such results are encouraging, researchers have yet to establish their direct relationship to crash occurrence.

Visibility Evaluations

Visibility evaluations of wider markings have been the focus of the most recent research evaluations and have shown positive results. The literature gives evidence that wider markings provide improvements in both nighttime end-detection distances and peripheral stimulation, which are believed to have a positive effect on vehicle-control measures and, consequently, crashes. Because of this, visibility improvements provided by pavement markings are often viewed as a proxy for improved roadway safety. However, as with intermediate measures, no quantifiable relationship between pavement marking visibility and crashes exists, and hence, no dollar value can be assigned.

Subjective Visibility Evaluations

Subjective visibility evaluations by agency personnel are a common and inexpensive method of evaluating wider markings. A significant number of transportation agency personnel commented in the survey on the long-range and peripheral visibility gains that are experienced when wider markings are used. In some cases, agencies have made wider marking policy decisions based on these results. The most recent example of this occurred within the Arizona DOT. Personnel at the Arizona DOT commented that a recent wider marking implementation program was based, at least in part, on both published visibility research and the dramatic visual impact (both day and night) of a piloted section of 6-inch markings alternated in mile-long sections with 4-inch markings (*unpublished information obtained from Arizona DOT*).

Detection Distance Evaluations

Detection distances are often measured in terms of the point at which the beginning or end of a marking section first becomes visible to an observer from a moving vehicle. The maximum nighttime detection distance (and subsequent preview time) of pavement markings is a commonly used method of quantifying improvements in pavement marking visibility. Zwahlen and Schnell tested nighttime detection distances of new pavement markings of various configurations, widths, and roadway geometries (*37*). They found that for young subjects there is a statistically significant increase in the average detection distance between a 4-inch and 8-inch-wide right edge line for a left curve (not the case for right curves or tangents). The average magnitude of this increase was approximately 20 meters (65.6 feet). It should be noted that the retroreflectivity of the markings was reported to be 1000 mcd/m^2/lux, which is substantially higher than markings generally used in practice. Recent field research by Schnell and Ohme has shown that for new white edge lines (approximate $R_L = 400$), increasing marking width from 4 to 6 inches has a significant (alpha = 0.10) positive effect on end-detection distances for both older and younger drivers under dry conditions at night (*32*). Curve detection distances using edge lines of varying widths and brightness were measured in a simulator study by Pietrucha, et al. (*33*). Marginal improvements in detection distances were found for the 8-inch vs. 4-inch edge lines for both older and younger drivers at low levels of marking brightness. The visibility model developed in COST 331, which is largely based on work by Adrian (*13*), also suggests that wider markings are visible at greater distances (*12*).

The literature search did not produce any objective driver visibility studies that used measures other than end-detection distance. While measuring detection distances provides an objective measure of visibility, such studies are related to central vision-oriented long-range driving tasks such as detecting an approaching curve. The literature showed that detection distances (and thus central vision-related tasks) are highly correlated to retroreflectivity, more so than marking width (*32,37,38,39*). This suggests that vision-related driving characteristics other than end-detection, such as peripheral visibility measures, may provide stronger measures of effectiveness for wider markings.

Peripheral Visibility Concepts and Related Evaluations

Short-range driving tasks, such as lane positioning, are considered to be highly dependent on peripheral vision. Increasing marking width would, in theory, play more of a role in improved peripheral visibility than long-range visibility because the visual angle of the marking is of a greater magnitude at closer distances (*40*). Therefore, in relation to the driving task, changes in marking width would be more noticeable in peripheral than in central vision. Additionally, the literature has shown that drivers do not appear to lower their speeds under lowered detection distances, suggesting that they tend to operate with shortened preview times (*41*). Shortened preview times translate to increased driver workload and stress level and an increased reliance on peripheral vision for navigation. It is for these reasons that peripheral visibility measures rather than end-detection measures may provide stronger evidence of the effect that wider markings have on driver visibility.

Unfortunately, no direct measures of peripheral detection as a function of marking width were found in the literature. However, some basic perception principles can be applied to the concept, suggesting improved peripheral detection with increased marking widths. Human vision is tuned to detect edges. Applied to the nighttime pavement marking situation, the area of transition from dark road surface to the bright pavement marking defines the edge to be detected. In the laboratory, perception of contrast is most commonly tested using sine wave gratings of varying spatial frequency (width) and contrast. A typical perception experiment of this type would have a display of alternating light and dark bars of a specific width (the spatial frequency), with the subject's task being to increase the contrast between the bars using a dial until the bars could be clearly detected. Conversely, the bars could be a fixed contrast and the subject could adjust the spatial frequency of the bars until they could be detected (*42*).

For this type of experiment, two findings are repeated throughout the literature that pertain to peripheral perception as a function of marking width. The first finding is that, in general, lower spatial frequencies (i.e., widely spaced bars) are easier to perceive at a given contrast level than higher spatial frequencies (i.e., very closely spaced bars). This concept is illustrated in Figure 4. Although the range of spatial frequencies tested in the laboratory is much greater than what would be seen on the roadway, even over a broad range of pavement marking widths, this is an area for future analysis.

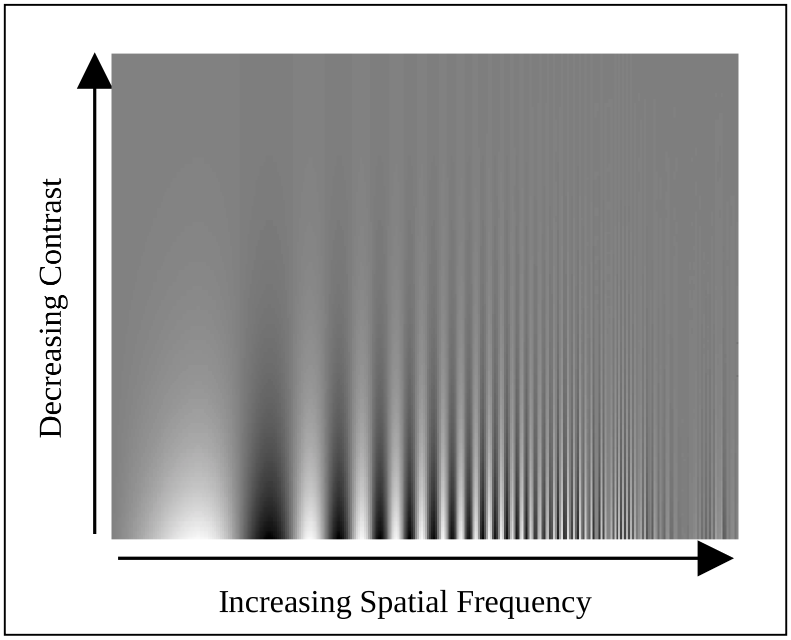

Figure 4. Luminance Contrast vs. Spatial Frequency (*43*).

The second and most interesting finding concerns the contrast sensitivity of peripheral vision. Laboratory research using sine wave gratings has shown that subjects can detect a lower spatial frequency (i.e., wider bars) up to 10 degrees off-axis from the point of fixation. Stimuli with narrower bars could not be detected this far in the periphery. This finding may apply directly to pavement marking width, suggesting that wider markings would be perceptible farther into the periphery (i.e., closer to the driver) than standard markings, thereby providing the more emphatic visual message that is often cited in subjective visibility and driver comfort evaluations but rarely quantified.

In other areas of traffic control, this interaction between size and peripheral detection has been evaluated by Zwahlen and Schnell (*44*). They found that to get equal detection in central and peripheral vision, peripheral targets had to be larger. They also found that by increasing the luminance of the targets through the use of fluorescent materials, the peripheral targets could be smaller than targets of ordinary color to achieve equal detection. Clearly, a tradeoff exists between size and luminance (and thus contrast) for peripheral visibility. More research is needed in this area before clear statements can be made regarding applicability to road markings. It should be pointed out that the researchers in no way suggest herein that the use of wider markings allows for decreased standards of retroreflectivity.

Researchers believe that intermediate crash measures, such as lane positioning, are related to peripheral vision. The most applicable of these research efforts is the recent simulator evaluation of line width vs. lane keeping by McKnight, et al. previously mentioned (*36*). Comparison of the lane keeping findings from this study (major improvements to lane keeping with wider markings at extremely *low* contrast levels) with the end-detection findings found elsewhere in the literature (better end-detection with wider markings at *high* contrast levels) suggest the need for more research on the effect of wider markings on peripheral vision before conclusions can be drawn.

Because characteristics of peripheral vision are not as well defined as those for central vision nor are they easily measured, measures of effectiveness related to driver workload may serve as suitable proxies. From an attentional allocation framework, wider lines may present a stable super-threshold target that requires less attention, thus freeing cognitive resources for other aspects of the driving task. The Positive Guidance philosophy states that lower level driving tasks involve keeping the vehicle on the road (*45*). This is where more visible pavement markings play a major role. If the task of keeping the vehicle on the road is made easier, more attention can be paid to higher order tasks. When the driver workload is high, for instance due to inclement weather or driver distraction, the added advantage of wider lines may be more apparent than under low-load driving situations. Additionally, it is likely that older drivers would display the largest improvements in workload measures due to the age-associated visual and cognitive declines.

Appropriate measures of driver workload could include physiological measures such as galvanic skin response, heart rate variability, or other measures of stress. These types of measures and their relationship to the driving task are described in detail in reference 46. Traditional traffic-related measures relating wider lines to lowered driver workload could include those related to secondary driving tasks (reaction times, detection distances, etc.) or primary driving tasks (lane placement or lane encroachment). Each of these types of evaluations could be considered quantitative visual performance and/or driver comfort measures and validate the findings from the subjective driver evaluations and surveys that suggest drivers feel more comfortable with wider markings.

BENEFITS OF WIDER MARKINGS

The five evaluation methods used by researchers and transportation agency personnel that have been presented in this report have been divided into two categories: those that produce results that can be assigned a dollar value and therefore can be included in a benefit/cost analysis, and those that produce results that cannot be included in a benefit/cost analysis because of the inability to assign a dollar amount to those benefits. The literature and contact with agency personnel have provided strong evidence that wider markings provide the following benefits to drivers, suggesting improved roadway safety:

- improved long-range detection under nighttime driving conditions (older drivers benefit the most),
- improved stimulation of the peripheral vision,
- improved lane positioning and other driver performance measures, and
- improved driver comfort.

Table 5 displays the relationship between the amount of evidence suggesting wider markings are effective and the ability to use those results in cost-effectiveness evaluations for each type of evaluation.

Table 5. Comparison of Wider Marking Evaluation Methods.

Evaluation Type	Type of Safety Measure	Is There Substantial Evidence Suggesting That Wider Markings are Effective?	Could Results be Used in a Benefit/Cost Analysis?
Driver Surveys	INDIRECT	YES	NO
Visibility	INDIRECT	YES	NO
Surrogate Measures	INDIRECT	YES	NO
Service Life	INDIRECT	INCONCLUSIVE	YES
Crashes	DIRECT	INCONCLUSIVE	YES

Unfortunately, for each evaluation type there appears to be an inverse relationship between the amount of evidence suggesting wider markings are beneficial and the ability to use the results in a benefit/cost analysis. Because benefit/cost analyses have historically served as an engineering benchmark by which to compare roadway countermeasures, the lack of conclusive benefit/cost data makes it difficult for some practitioners to justify the use of wider markings as an appropriate countermeasure (safety or otherwise). However, a majority of the benefits suggesting that wider markings are effective are associated with indirect measures of safety. With that, it becomes apparent that two schools of thought exist when considering the effectiveness of wider vs. 4-inch pavement markings:

1. The effectiveness of wider markings as a highway safety improvement cannot be justified without some form of conclusive cost-quantifiable data to support this claim, such as crash reductions.
2. Recognizing that conclusive cost-quantifiable data are likely not available and would be extremely difficult to measure, other proven measures of effectiveness are appropriate to justify the use of wider markings because such measures *imply* improved safety, and thus serve as a proxy for crash reductions.

Results from the agency survey provide substantial evidence that the latter is the preferred school of thought among agencies currently using wider markings. Tables 1, 2 and 3 allow for comparison of the reasons cited by agencies to justify the use of wider markings vs. basis for implementation and benefits measured. As expected, common reasons for using wider markings include visibility improvements, benefits to older drivers, crash reductions, and improved driver comfort. However, the decision to implement is usually based on subjective or indirect safety measures. Additionally, more than half of the agencies using wider markings have not measured the benefits that wider markings may provide to the driver. Those that have measured the benefits have done so based heavily on subjective evaluations such as driver opinions or subjective visibility comparisons. Thus, the survey data clearly suggest that an overwhelming number of agencies that use wider markings do so on the basis of indirect or implied measures of improved safety.

CHAPTER 5
FINDINGS

Four inches has been the standard width for most longitudinal pavement marking lines for over 50 years. Over the last 20 years, the use of long lines wider than 4-inches has increased as the driving population has aged and agencies have gained knowledge about the visibility needs associated with markings. Many agencies are now using wider markings, but there is no coordinated use and little documentation on the agencies' experiences related to the use of wider markings. This project was established with two objectives: 1) identify the current use of wider markings among transportation agencies in the U.S., Canada, and other countries, and 2) identify information in the technical literature that addresses the advantages and disadvantages of wider markings, including visibility, costs, safety, and operational impacts. The current use of wider markings was identified through a survey of U.S. and international agencies. The survey, conducted in mid-2001, indicates that 29 of the 50 state DOTs in the U.S. use wider markings to some degree, with most agencies expressing satisfaction with their use. The most significant finding is that the use of wider markings by state DOTs in the U.S. is most prevalent east of the Mississippi River. The survey also showed that some agencies that are currently not using wider markings are considering their use. The findings indicate that the use of wider markings will continue to increase both in the total number of agencies using wider markings and the extent to which they are used in individual agencies. The technical literature contains several studies of wider markings, with varying degrees of detail in the analysis approaches. Overall, the technical literature indicates that is it difficult to determine quantifiable economic benefits for wider markings.

Wider markings typically cost more to implement because of the greater quantity of material compared to the typical 4-inch line. Because of the increased costs, most agencies prefer to have some type of evidence of the benefits of wider markings to justify their use. This report describes five main methods for evaluating the effectiveness of wider pavement markings:

- crash evaluations,
- service life analyses,
- visibility measures,
- intermediate measures, and
- driver opinion surveys/comments.

Traditional evaluation methods have centered on crash studies, mainly because of the ability to translate these results (assuming significant differences exist) into benefit/cost ratios that can demonstrate an economic benefit. However, there is a lack of conclusive data associated with the crash-reduction effects of wider markings. This is primarily due to the difficulty of conducting before-and-after studies where the only change is the width of the marking. Because of the nature of the types of crashes related to wider markings, the type of crash study needed to show a statistically significant difference requires a larger sample size and typically occurs over a longer period of time. During the study period, there are often other influential factors that confound the analysis such as differences in marking retroreflectivity, changes in the pavement surface, changes in traffic volumes or development, and other factors. As a result, the cost-effectiveness of wider markings has not been well established on the basis of crash reductions.

Likewise, service life effects of wider markings have not been thoroughly evaluated to document the economic benefits of wider markings. There are a limited number of studies on the increase in service life that can be achieved by using wider markings. Some of the information suggests that wider markings have greater durability from a visibility standpoint than 4-inch markings. But the available information is not sufficient to provide a quantifiable economic benefit to wider markings.

Fortunately, there are other methods that can provide conclusive evidence that wider markings are beneficial and imply improved safety. For example, wider markings have been shown to provide benefits to driver visibility measures such as improved long-range detection of the markings at night and improved surrogate measures, such as lane keeping. Wider markings likely benefit older drivers the most, due to age-associated declines in visual and cognitive capabilities. Past research findings along with the scientific literature suggest that wider markings may have the greatest effect on driver measures related to peripheral vision. Although no direct measurements of peripheral visibility for wider vs. standard markings were found in the literature, evidence suggests that the improved peripheral signal that is provided by the markings leads to lessened driver workload, improved driver comfort and improved driver performance measures, such as lane keeping. Evidence suggests that transportation agencies and researchers alike are increasingly turning to the aforementioned indirect safety measures to justify the use of wider markings. Finally, where wider markings have been implemented by agencies, the driving public has generally been very supportive. While public support is not a quantitative measure that can be used to assess the cost-effectiveness of markings, it has been a factor in the implementation process in a few states.

Based on the findings from the literature and review of agency practices, wider markings appear to have the greatest benefit when used in the following situations:

- locations where a higher degree of lane or roadway definition is perceived as needed, including:
    - horizontal curves,
    - roadways with narrow shoulders or no shoulders, and
    - construction work zones;
- locations where low luminance contrast of markings is common; and
- locations where older drivers are prevalent and thus require added roadway visibility under all conditions.

The results of this effort indicate that wider markings are being used in a significant proportion of the United States and that the use of wider markings is growing as agencies continue to search for methods of meeting the needs of older drivers. The information provided by many agencies indicate that the implied safety benefits of wider markings are sufficient to justify implementation of wider markings, given the difficulty in obtaining quantitative data indicating the benefits.

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APPENDIX A
SURVEY INSTRUMENT FOR U.S./CANADA WIDER MARKINGS SURVEY

INTRODUCTION

Dear Survey Respondent:

Thank you very much taking the time to participate in this important survey. You have been chosen to participate in this survey because of your expertise as a traffic engineer. Currently, the Operator Performance Laboratory of the University of Iowa and the Texas Transportation Institute are independently conducting pavement marking visibility and applications research. The research in Iowa is funded by Iowa Department of Transportation, and the research at TTI is sponsored by the American Glass Bead Association. Although the teams are conducting separate pavement marking studies, we decided to team up on this survey to minimize the efforts of respondents and because both teams are interested to learn more about the use of wide pavement markings. Your answers will help us in obtaining the information about pavement marking applications and specifications in your state, and the results of this survey will be used to develop a report that provides a snapshot of the pavement marking application practices as they relate to improving visibility and driver safety across the U.S. Please read the following instructions carefully and answer all of the questions to the best of your knowledge as a traffic engineer in your agency.

INSTRUCTIONS

Please answer the following questions. The questionnaire is generally designed as a multiple-choice format. Each question has a comment box, on which you can specify any related information. Each question has instructions on whether you may check more than one checkbox. In answering the questions, follow the applicable arrow paths if you select a checkbox which has an arrow underneath. There are no right or wrong answers, we are solely interested in your agency's practices as they relate to pavement marking applications, and in your opinion and expertise as a traffic engineer. Please read each question carefully and do not hesitate to make any comments about any of the questions in the associated comment boxes. After completing the questionnaire, click on the "Submit Form" button to finish the survey. The "Reset Form" button will clear the entries you have entered up to that point.

1. Is your agency using longitudinal pavement markings that are wider than the 4-inches width normally specified in the MUTCD? *(Check one)*

- ☐ Yes
  Our typical wide line is **_______**inches wide
  The wider line is used for:
  - ☐ Wider edge lines only
  - ☐ Wider center (lane) lines only
  - ☐ Both wider center (lane) lines and edge lines
- ☐ No....(Skip to end)
- ☐ I don't know

Comments

2. Please elaborate on the use of markings that are wider than 4-inches, i.e., where and why are you using markings that are wider than 4-inches?

3. How did your agency go about making a decision to implement markings that are wider than 4-inches (e.g., research study, field/pilot evaluation, review of the technical literature, success in other agencies, etc.)?

4. Is documentation available regarding the processes described in the previous question (3) (e.g., research reports, evaluation findings, survey results, etc.)?

5. What benefits did you expect from implementing markings that are wider than 4-inches?

6. Please describe any differences between the expected and the actual results of implementing markings that are wider than 4-inches?

7. Has crash data changed as a result of using markings that are wider than 4-inches?

8. Have you seen any drawbacks of using markings that are wider than 4-inches?

9. What factors should be considered in determining whether to use markings that are wider than 4-inches?

10. How do you apply pavement markings that are wider than 4-inches? *(Check all that apply)*

- ☐ Raise nozzles to achieve wider markings
- ☐ Reduce application speed
- ☐ Increase flow rates of materials
- ☐ Use wider nozzles
- ☐ Other. Please explain:

APPENDIX B

AGENCY RESPONSES TO U.S./CANADA WIDER MARKINGS SURVEY

Appendix B contains the full agency responses to the internet/telephone survey that was administered by TTI and the University of Iowa in the summer of 2001. Responses have been summarized where necessary for brevity. To keep the size of this appendix at a minimum, agencies indicating that they do not use wider markings were not included in the response summary tables in this appendix unless further response or comments were given. The agencies that are not currently using wider markings and are not included in the response summary tables are as follows:

United States:
Alaska DOT
Arkansas DOT
California DOT
Colorado DOT
Hawaii DOT
Minnesota DOT
Missouri DOT
New Jersey DOT
North Dakota DOT
Ohio DOT
Utah DOT
Washington DOT
West Virginia DOT
Wisconsin DOT
Wyoming DOT
City of Scottsdale, Arizona
City of Tempe, Arizona

Canada:
Alberta DOT
British Columbia DOT
Manitoba DOT
New Brunswick DOT
Nova Scotia DOT

	Alabama DOT	**Arizona DOT**	**Connecticut DOT**
Are Wider Markings Used	**YES**	**YES**	**YES**
Typical Width	**6”**	**6"**	**6"**
Line Types	Center/Lane/Edge	Center/Lane/Edge	Lane lines only
Roadway Types Where Wider Markings are Used	All routes	Various locations throughout state - still in the implementation phase; most urban freeways in Phoenix and Tucson have been striped with 6” lines	All freeways - other major multilane routes by discretion
Reason for Using	NR	Improve visibility	Improve visibility
Basis for Implementation	Pilot evaluation; other states’ experience	Review of technical literature; other agencies' successes; cumulative judgment of state traffic engineers	Decision made in 1980s based on discussion between state engineers and administrators who concluded based on primarily subjective evidence that width plays the most important role in the visibility of the marking
Documentation of Implementation Process	Unsure	Yes	None
Expected Benefits	Improved visibility, fewer accidents associated with failure to see markings	Increased driver comfort; crash reductions	Improved visibility
Observed Benefits	Reduction of crashes in mid-1980s FHWA study by Hughes, et al.	Still in implementation phase, not enough “after” time	No benefits have been measured
Observance of Crash Reductions	Reporting period not long enough yet with new implementation; crash study by Hughes, et al. showed crash reduction on certain 2-lane roadways with 8-inch edge lines	Still in implementation phase, not enough “after” time	Has not been evaluated
Drawbacks	Cost	Cost	Cost
Factors to be Considered Prior to Implementation	Speed; typical section (presence or absence of paved or bituminous treated shoulders, curbs, etc.); pavement width; AADT; complexity of lanes; transitions; turning movements; crash studies	Safety; cost; retrofitting of existing maintenance equipment	NR

NR = No Response.

	Delaware DOT	Florida DOT	Georgia DOT
Are Wider Markings Used	**YES**	**YES**	**YES**
Typical Width	**6"**	**6"**	**5"**
Line Types	Center/Lane/Edge	Center/Lane/Edge	Center/Lane/Edge
Roadway Types Where Wider Markings are Used	Interstate only	All routes	All routes
Reason for Using	NR	Large older driver population	Improve visibility
Basis for Implementation	NR	FHWA pilot program in the late 1980s; crash data analysis; older driver interviews	Unknown
Documentation of Implementation Process	NR	Yes	Unknown
Expected Benefits	Improved visibility both day and night	Provide improved guidance and safety for older drivers	Greater detection distances; improved safety
Observed Benefits	NR	Favorable older driver response	Greater detection distances; improved safety; longer service life
Observance of Crash Reductions	NR	Unable to perform a reliable crash study of this type	Has not been evaluated
Drawbacks	None	None	None
Factors to be Considered Prior to Implementation	ADT	Management approval; customer surveys; driver guidance research; older driver population	Driver age; longer service life

NR = No Response.

	Indiana DOT	Idaho DOT	Illinois DOT
Are Wider Markings Used	**YES**	**NO**	**YES**
Typical Width	**5"**	**-**	**5" / 6"**
Line Types	Lane lines only	-	Varies by district
Roadway Types Where Wider Markings are Used	Interstate only	-	Varies by district
Reason for Using	Perceived visibility improvements	-	Improve visibility
Basis for Implementation	Previously, all multilane roadways were striped with 5" lane lines, but in the 1980s budget restrictions and lack of technical literature cause the state to cutback to interstate only	-	Decision made by the district engineers
Documentation of Implementation Process	Unsure	-	None
Expected Benefits	Improved visibility	-	Better visibility
Observed Benefits	No benefits have been measured	-	NR
Observance of Crash Reductions	Has not been evaluated	Wider markings aren't yet considered for use because there is no hard crash evidence	Has not been evaluated
Drawbacks	Cost	-	Cost
Factors to be Considered Prior to Implementation	NR	-	If improved visibility is desired; cost of additional material

NR = No Response.

	Iowa DOT	**Kansas DOT**
Are Wider Markings Used	**NO**	**YES**
Typical Width	**-**	**6" mostly - some 8" edge lines at spot locations**
Line Types	-	Edge lines on two-lane routes, lane lines on interstate
Roadway Types Where Wider Markings are Used	-	Lane lines on all interstates; edge lines on various narrow two-lane routes that are winding, hilly or have high occurrence of ROR - implementing more each year
Reason for Using	-	Constraints on roadway width; run off the road accidents; or a winding, hilly roadway; older drivers
Basis for Implementation	-	For two-lane roads: field pilot evaluation in location with excessive ROR crashes; for interstates: unsure - lane lines have been wider for years
Documentation of Implementation Process	-	Unsure
Expected Benefits	-	Crash reduction; reinforcement of roadway limits
Observed Benefits	Visibility study performed by Schnell at the University of Iowa and sponsored by Iowa DOT showed that wider edge lines improved preview distances for older drivers under dry conditions at night	NR
Observance of Crash Reductions	-	An internal multi-year before and after review of the crashes at the pilot location showed no appreciable differences
Drawbacks	-	None
Factors to be Considered Prior to Implementation	-	Increased cost; whether the roadway has any unforgiving characteristics such as width, sharp curves, narrow bridges, steep inclines with curves, or lack of good shoulders

NR = No Response.

	Kentucky DOT	**Louisiana DOT**	**Maine DOT**
Are Wider Markings Used	**YES**	**NO**	**YES**
Typical Width	**6"**	**-**	**6"**
Line Types	Center/Lane/Edge	-	Center/Lane/Edge
Roadway Types Where Wider Markings are Used	Freeways only	-	Divided highways
Reason for Using	Perceived safety enhancement; aesthetics	-	To provide consistency with the major Maine DOT controlled highways and the separately controlled Maine Turnpike
Basis for Implementation	Policy change based on pilot evaluation and other states' successes	-	Pilot evaluation and other research studies
Documentation of Implementation Process	None	-	None
Expected Benefits	Improved nighttime visibility; improved safety; increased driver comfort; improved aesthetics	-	Longer service life; better nighttime visibility
Observed Benefits	Improved nighttime visibility; improved safety; increased driver comfort; improved aesthetics	-	NR
Observance of Crash Reductions	Has not been evaluated	Wider Markings were considered for use in early 2001. They were not implemented because no hard crash reduction data were available to justify increased cost	A small crash study in the late 1970s showed that using 6" and 8" edge lines produced no significant ROR crash reductions when compared to 4" edge lines; the whereabouts of this study are unknown
Drawbacks	None	-	None
Factors to be Considered Prior to Implementation	Cost	-	NR

NR = No Response.

	Maryland DOT
Are Wider Markings Used	**YES**
Typical Width	**5" mostly - some 10" edge lines at spot locations**
Line Types	Center/Lane/Edge
Roadway Types Where Wider Markings are Used	All routes (Note: markings were 6" until the mid-1980s when it was determined that 5" lines were easier to spray. 10" edge lines are now being applied experimentally at some hazardous locations)
Reason for Using	Improve visibility and driver comfort
Basis for Implementation	Started implementing 6" lines in early 1980s at high accident locations on horizontal curves. Driver surveys in mid 1980s showed that drivers were not happy with the current 4" striping statewide, which prompted the agency to implement 6" markings across the board. The wider markings received an overwhelmingly positive response from the driving public. Shortly thereafter, the decision was made to cutback to 5" lines because they were easier to place. Other factors that prompted the decision to implement wider lines include a research study, field/pilot evaluation, review of the technical literature, success in other agencies
Documentation of Implementation Process	None
Expected Benefits	Greater visibility from distance or side angle, accident reduction, overall improved “positive guidance”
Observed Benefits	Fewer complaints and the belief that the motorist has an improved comfort level
Observance of Crash Reductions	A small crash study was performed on two rural highways where 10" edge lines were applied as an experimental crash countermeasure, which produced inconclusive results
Drawbacks	Cost
Factors to be Considered Prior to Implementation	Need for safety and visibility

NR = No Response.

	Massachusetts DOT	**Michigan DOT**	**Mississippi DOT**
Are Wider Markings Used	**YES**	**YES**	**YES**
Typical Width	**6"**	**8"**	**6"**
Line Types	Center/Lane/Edge	Center/Lane/Edge	Center/Lane/Edge
Roadway Types Where Wider Markings are Used	Freeways only, considering lower-type roadways also	Only used where evidence of ROR or sideswipe type crashes and presence of horizontal or vertical curves	Being phased in on all routes
Reason for Using	To combat driver fatigue	To reduce ROR and sideswipe crashes	Improve visibility
Basis for Implementation	Based on other states' successes	NR	NR
Documentation of Implementation Process	None	Unsure, decision made by regional staff	NR
Expected Benefits	Improved visibility; improved safety	Reduction of ROR and sideswipe crashes	NR
Observed Benefits	No benefits have been measured	Unknown	Improved visibility
Observance of Crash Reductions	Has not been evaluated	Has not been evaluated	Has not been evaluated
Drawbacks	Slight cost increase	Costs; striping patterns are affected	Cost
Factors to be Considered Prior to Implementation	NR	Value to the motorist vs. cost of implementation and upkeep	Cost

NR = No Response.

	Montana DOT	Nebraska DOT	Nevada DOT
Are Wider Markings Used	**NO**	**YES**	**YES**
Typical Width	**-**	**5"**	**8"**
Line Types	-	Edge lines only	Center/Lane/Edge
Roadway Types Where Wider Markings are Used	-	All routes 5" edge lines; however, some districts are now experimenting with 4" edge lines	Interstate only
Reason for Using	-	NR	Older drivers
Basis for Implementation	-	Field pilot evaluation	Other states' experience (North Carolina)
Documentation of Implementation Process	-	None	None
Expected Benefits	-	Fewer ROR crashes	Improved visibility
Observed Benefits	-	NR	Favorable public response
Observance of Crash Reductions	Wider markings were used as part of an older driver corridor study in the early 1990s, which also included sign and geometric upgrades and an educational component. Crashes were reduced 18 percent in the after period for older drivers and 8.3 percent overall. Regardless, wider markings have since seen only limited use statewide	Has not been evaluated	Has not been evaluated
Drawbacks	-	Cost	Cost
Factors to be Considered Prior to Implementation	-	Population demographics; crash experience; benefit/cost	Older drivers

NR = No Response.

	New Hampshire DOT	**New Mexico DOT**	**New York DOT**
Are Wider Markings Used	**YES**	**NO**	**YES**
Typical Width	**6"**	**-**	**6"**
Line Types	Center/Lane/Edge	-	Center/Lane/Edge
Roadway Types Where Wider Markings are Used	Freeways only	-	Interstates and parkways
Reason for Using	Wider markings are better	-	Improve visibility
Basis for Implementation	Consensus between NHDOT and local FHWA office	-	Positive results from other agencies
Documentation of Implementation Process	None	-	None
Expected Benefits	Increased day and night visibility	-	Improved driver comfort; improved vehicle lane positioning; possible accident reduction
Observed Benefits	No benefits have been measured	-	No benefits have been measured
Observance of Crash Reductions	Has not been evaluated	A crash study by Hall in the early 1980s showed no significant decrease in crashes when 8-inch wide edge lines were applied to two-lane rural roads with high accident rates	Has not been evaluated
Drawbacks	Negligible cost increases	-	Cost
Factors to be Considered Prior to Implementation	NR	-	Budget

NR = No Response.

	North Carolina DOT	Oklahoma DOT	Oregon DOT
Are Wider Markings Used	**YES**	**YES (pilot project)**	**YES**
Typical Width	**6"**	**5"**	**8"**
Line Types	Center/Lane/Edge	Lane lines only	Lane lines only
Roadway Types Where Wider Markings are Used	Wider edge lines on all routes; wider center/lane lines on case-by-case basis	I-235 pilot project; considering full implementation for all lines on all routes	8-inch solid lane lines used where lane changing is discouraged, such as in construction zones or on hills; in the past, 6-inch lines were experimented with in fog areas
Reason for Using	NR	More area is covered by the markings making them better for older drivers and potential durability improvements	To emphasize lane keeping
Basis for Implementation	Engineering study; past performance; positive driver feedback from early 1990s survey	Are currently performing a survey of state DOTs as to the use of wider markings which will be used for determining whether or not to fully implement wider markings on all state routes	NR
Documentation of Implementation Process	None	Will have an internal report prepared by early 2002	NR
Expected Benefits	Improved visibility; fewer crashes	Improved durability; improved visibility for older drivers; crash reductions	Better lane positioning
Observed Benefits	Overwhelmingly favorable public response although no documentation	Too early to tell	NR
Observance of Crash Reductions	1995 crash study showed inconclusive results	Informally compared crash history for before and after periods and found no changes	NR
Drawbacks	Cost	20 percent increase in cost	NR
Factors to be Considered Prior to Implementation	Number of lanes; traffic volume; type of facility	Older drivers; cost increases	NR

NR = No Response.

	Pennsylvania DOT	**Rhode Island DOT**	**South Carolina DOT**
Are Wider Markings Used	**YES**	**YES**	**YES**
Typical Width	**6"**	**6"**	**6"**
Line Types	Lane lines only	Center/Lane/Edge	Center/Lane/Edge
Roadway Types Where Wider Markings are Used	Multilane roadways	Freeways only	Interstate only
Reason for Using	Improve visibility of skip patterns; provide better guidance, especially for high-speed motorists	NR	Improve visibility
Basis for Implementation	Policy decision based on experience and personal opinion	Likely based on other states' practices	Success of other agencies; field/pilot evaluation
Documentation of Implementation Process	None	Unsure	None
Expected Benefits	Improved safety; driver comfort	Improved visibility; driver comfort	Improved visibility on higher speed interstate routes; markings appear proportional to speed and surroundings
Observed Benefits	NR	Improved visibility; driver comfort; positive public response	Positive public response
Observance of Crash Reductions	Has not been evaluated	Has not been evaluated	Has not been evaluated
Drawbacks	Cost; slight decrease in production	Negligible cost increases	Very slight cost increases
Factors to be Considered Prior to Implementation	NR	NR	Available lane widths; speeds; surface types

NR = No Response.

	South Dakota DOT	Tennessee DOT	Texas DOT
Are Wider Markings Used	**YES**	**YES**	**NO**
Typical Width	**8"**	**6"**	**-**
Line Types	Edge lines only	Center/Lane/Edge	-
Roadway Types Where Wider Markings are Used	Two-lane roads with 2-ft shoulder or less	Freeways only	-
Reason for Using	Improve visibility and reduce the occurrence of ROR crashes	Improve visibility; older drivers	-
Basis for Implementation	8" edge lines implemented in mid 1980s on certain hazardous routes in the Black Hills as a ROR countermeasure; now going to statewide implementation of 8" edge lines on all routes with 2-ft shoulder or less	Experimented with 6" on a singe field/pilot evaluation and subjectively decided to make it policy for all access controlled highways	-
Documentation of Implementation Process	None	None	-
Expected Benefits	Improved visibility, improved safety	Improved safety	-
Observed Benefits	No benefits have been measured	No hard data, but it is assumed that they improve safety	-
Observance of Crash Reductions	Has not been evaluated	Has not been evaluated	An internal before-after study in the early 1980s compared ROR crashes on over 200 miles of rural highways striped with 8-inch edge lines to that of control sections striped with 4-inch lines. No significant crash reduction was found
Drawbacks	Slight cost increase	None	-
Factors to be Considered Prior to Implementation	NR	ADT	-

NR = No Response.

	Vermont DOT	Virginia DOT
Are Wider Markings Used	**YES**	**YES**
Typical Width	**6"**	**6"/8"**
Line Types	Center/Lane/Edge	Center/Lane/Edge
Roadway Types Where Wider Markings are Used	All interstate; in the process of implementing 6" on all other freeways	6" on all interstates and various other routes in Northern Virginia District; 8" used across the state in hazardous areas such as at approaches to narrow bridges or fog areas; considering statewide implementation
Reason for Using	Improve visibility under low visibility conditions	To provide consistency between the states around the D.C. area; improve safety
Basis for Implementation	Poor marking quality brought about the decision to begin implementing wider markings and durable materials	Implemented in mid 1990s to ensure that motorists are not provided with a narrower marking as they cross into Virginia along the beltway; also FHWA and AASHTO recommendations; favorable public response
Documentation of Implementation Process	None	None
Expected Benefits	Improved marking visibility and more durable markings	Enhanced safety
Observed Benefits	Improved visibility under low visibility conditions; good customer response	NR
Observance of Crash Reductions	Has not been evaluated	Unknown for recent installations; however, refer to 1987 wider edge line study by Cottrell that found no significant ROR crash reductions on two-lane roads in Virginia
Drawbacks	None; cost increases have been negligible	Cost
Factors to be Considered Prior to Implementation	NR	Driver needs; accidents; cost-effectiveness

NR = No Response.

	Garden State Parkway	Indiana Tollroad	New York State Thruway
Are Wider Markings Used	**YES**	**YES**	**YES**
Typical Width	**6"**	**6"**	**6"**
Line Types	Center/Lane/Edge	Center/Lane/Edge	Center/Lane/Edge
Roadway Types Where Wider Markings are Used	All routes	All routes	All routes
Reason for Using	Improve visibility for high speed traffic	Improve nighttime visibility for older drivers	Enhance safety and visibility of markings - especially for older drivers
Basis for Implementation	Unknown	Engineering decision	Need for better visibility
Documentation of Implementation Process	None	None	NR
Expected Benefits	Improved visibility	Improved visibility for older drivers; improved safety	Better visibility; enhanced safety
Observed Benefits	Subjectively improved visibility; good customer response	Improved visibility at night; good customer response	NR
Observance of Crash Reductions	Has not been evaluated	Has not been evaluated	NR
Drawbacks	Cost	NR	NR
Factors to be Considered Prior to Implementation	NR	NR	NR

NR = No Response.

	Ohio Turnpike	Oklahoma Tollroad	Pennsylvania Turnpike
Are Wider Markings Used	**YES**	**YES**	**YES**
Typical Width	**6"**	**6"**	**6"**
Line Types	Center/Lane/Edge	Lane lines only	Lane lines only (considering 8" lane lines and 6" edge lines)
Roadway Types Where Wider Markings are Used	All routes	All routes	All routes
Reason for Using	Unknown	Improve nighttime visibility	Improve visibility
Basis for Implementation	Unknown	Engineering decision	Unknown
Documentation of Implementation Process	None	None	None
Expected Benefits	Unknown	Improved visibility; improved safety	Improved visibility
Observed Benefits	Improved visibility, positive public feedback	Improved visibility; fewer complaints	None
Observance of Crash Reductions	Has not been evaluated	Has not been evaluated	Has not been evaluated
Drawbacks	Slight cost increase	NR	NR
Factors to be Considered Prior to Implementation	NR	NR	NR

NR = No Response.

	New Jersey Turnpike	Ontario DOT
Are Wider Markings Used	**YES**	**YES**
Typical Width	**6"**	**8"**
Line Types	Center/Lane/Edge	Edge line/Lane line
Roadway Types Where Wider Markings are Used	All routes	8" edge line used adjacent to a median barrier on one freeway; 8" edge line/lane line used at end of climbing or passing lanes on 2-lane highways
Reason for Using	Improve visibility under low visibility conditions such as fog	Improve visibility needed at transition areas
Basis for Implementation	Engineering decision	NR
Documentation of Implementation Process	None	NR
Expected Benefits	Improved visibility; improved safety	Improved visibility
Observed Benefits	Noticeable difference in visibility between 6" and 4"	NR
Observance of Crash Reductions	Has not been evaluated	NR
Drawbacks	NR	Increased paint tracking when first applied; increased cost
Factors to be Considered Prior to Implementation	NR	NR

NR = No Response.

APPENDIX C
SURVEY INSTRUMENT FOR INTERNATIONAL WIDER MARKINGS SURVEY

Thank you very much for taking the time to participate in this important survey. The Texas Transportation Institute (TTI) is currently performing a study of the use of wider-than-standard pavement markings throughout the world. The results of this survey will be used to develop a report that provides a snapshot of the pavement marking application practices as they relate to improving visibility and driver safety. If you are not the correct person to complete the survey within your agency, please forward this to the correct person.

Name:
Job Title:
Agency:
Country:
Mailing Address:
Phone Number:
Email Address:

International Wider Longitudinal Pavement Markings Survey

1. To your knowledge, has your roadway agency for any reason increased the width of longitudinal pavement markings, including: edge lines, centerlines and lane lines?

2. If so, please describe on the use of the wider markings, specifically where are they used and why did your agency begin using the wider pavement markings?

3. How did your agency decide to implement the wider markings? (Examples include: research study, field/pilot evaluation, review of the technical literature, success in other agencies, etc.)

4. What benefits were expected by your agency from implementing wider markings? (Examples include: improved visibility at night, better lane placement of vehicles, reduction in crashes, favorable public opinion, etc.)

Have these benefits been realized?

5. Has your agency documented any impacts of implementing the wider markings through any formal or informal studies?

May we receive a copy?

6. Specifically, has crash data changed as a result of using the wider longitudinal pavement markings?

Thank you for your time. Please contact me if you have any questions.

APPENDIX D
RESPONSES TO INTERNATIONAL WIDER MARKINGS SURVEY

	Denmark	Germany	Hungary	Iceland
Have Marking Widths Been Increased?	**NO**	**NO**	**NO**	**YES**
Typical Width		-	-	**20 cm**
Line Types		-	-	Edge lines only
Where are the Wider Markings Used?		-	-	Construction of a new facility with wider lanes prompted the decision to use a "double width" dashed edge line (3m:3m)
Purpose for Using Them		-	-	Maintains the visibility, while changing the line pattern
Basis for Implementation	In early 90's, thermo edge lines were implemented to replace the former light stone surface treatment that was the previous edgeline treatment. In the process, widths were reduced from 0.5 m to 0.3 m, but the retro was increased substantially.	No width increases because it has not yet been determined how to calculate or predict the number of accidents which could be prevented by better markings	Marking widths have not been increased due to economic reasons	Engineering decision
Expected Benefits	Improved nighttime visibility and more comfortable driving	-	-	Improved visibility
Have These Benefits Been Realized?	Yes, visibility improvements verified by the COST 331 model	-	-	No
Documented Impacts from Using the Wider Markings		-	-	None
Observance of Crash Reductions		-	-	Has not been evaluated

	Ireland	Mexico	Netherlands	South Africa	Sweden
Have Marking Widths Been Increased?	**YES**	**YES**	**NO**	**YES**	**YES**
Typical Width	**15 cm**	**15 cm**	-	**20 cm**	**15 cm**
Line Types	Centerline/Edge line	Center/Lane/Edge	-	Centerline/Edge line	Centerline/Lane line
Where are the Wider Markings Used?	On national highways, wider lines are used as edge lines and carriageway centerline	Major highways and other locations with poor visibility	-	Edge lines where ROR crash risk is present; centerline on two-way undivided roadways	Major highways (ADT > 4000)
Purpose for Using Them	Better visibility and "more forceful" in defining edges	The need for extra visibility on high speed roadways	-	Improved visibility from wider markings	Improved visual guidance at night
Basis for Implementation	Pilot scheme; review by a small group of engineers; anecdotal comments (favorable) from road users	Internal research study and pilot study - both recommending wider markings	Different patterns and stripe/gap spacing are being considered for edge lines	Wider markings were specified after reviewing technical lit. that concluded wider markings improve visibility	Discussion amongst regions concluded that the most important highways must be improved; the program developed in COST 331 is now being used to design markings for such highways
Expected Benefits	Improved visibility; better lane/edge definition, and favorable comments from users and police	Reduced crashes; better lane placement; better speed control	-	Improved visibility under adverse conditions (i.e., poor weather, darkness or both) leading to reduced risk of head-on and ROR crashes	Improved visual guidance on unlit highways at night
Have These Benefits Been Realized?	Yes	Yes	-	Unsure	Yes
Documented Impacts from Using the Wider Markings	None	None	-	None	The effect of wider markings on driver comfort and traffic safety has been recently investigated by Karin Brundell-Freij at the University of Technology in Lund, Sweden; results show that it is difficult to make traffic-safety conclusions as to their effects based on a single parameter such as improved visibility
Observance of Crash Reductions	Has not been evaluated	Improved striping and signing combined have shown a decrease in crashes	-	Has not been evaluated	Has not been evaluated