ILLINOIS CENTER FOR TRANSPORTATION

CIVIL ENGINEERING STUDIES
Illinois Center for Transportation Series No. 22-010
UILU-ENG-2022-2010
ISSN: 0197-9191

Crash Modification Factors for Contrast Pavement Markings on Light-Colored Pavement

Prepared By
Michael Williamson
Sumit Singh
Indiana State University

Research Report No. FHWA-ICT-22-010

A report of the findings of

ICT PROJECT R27-223
Crash Modification Factors (CMFs) for Contrast Pavement Markings on Light-Colored Pavement

https://doi.org/10.36501/0197-9191/22-010

Illinois Center for Transportation

August 2022

TECHNICAL REPORT DOCUMENTATION PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA-ICT-22-010	N/A	N/A
4. Title and Subtitle Crash Modification Factors for Contrast Pavement Markings on Light-Colored Pavement		**5. Report Date** August 2022 **6. Performing Organization Code** N/A
7. Authors Michael Williamson and Sumit Singh		**8. Performing Organization Report No.** ICT-22-010 UILU-2022-2010
9. Performing Organization Name and Address Illinois Center for Transportation, Department of Civil and Environmental Engineering, University of Illinois at Urbana-Champaign, 205 North Mathews Avenue, MC-250, Urbana, IL 61801		**10. Work Unit No.** N/A **11. Contract or Grant No.** R27-223
12. Sponsoring Agency Name and Address Illinois Department of Transportation (SPR), Bureau of Research, 126 East Ash Street, Springfield, IL 62704		**13. Type of Report and Period Covered** Final Report 8/16/20–8/15/22 **14. Sponsoring Agency Code**

15. Supplementary Notes

Conducted in cooperation with the U.S. Department of Transportation, Federal Highway Administration.
https://doi.org/10.36501/0197-9191/22-010

16. Abstract

Roadway departure crashes are a leading cause of fatal and severe injury crashes on high-speed roadways. The objective of this project was to evaluate the safety benefits of contrast pavement markings and to develop a benefit-cost analysis tool for use in project selection. A nationwide survey was developed and deployed to departments of transportation and highway agencies that identified the use of contrast pavement markings at the national level. The survey further determined that no safety benefits have been quantified by any other agency. A before-and-after study using an empirical Bayes approach was conducted on 70 miles of urban/suburban roadways and included data from six states. Crash modification factors were developed for three roadway types at three crash severity levels, all showing a decrease in crashes with the use of contrast pavement markings. The results of this research can be used to predict the type of crash reductions that can be expected when installing contrast pavement markings on high-speed roadways. A benefit-cost analysis tool was also developed and can be used to evaluate the expected reduction in roadway departure crashes on a given roadway section at each crash severity level. The benefit-cost tool provides justification for the extra cost of contrast pavement markings.

17. Key Words	18. Distribution Statement
Crash Modification Factor, Contrast Pavement Markings, Survey, Benefit-Cost Analysis, Crash Reduction, Highway Safety	No restrictions. This document is available through the National Technical Information Service, Springfield, VA 22161.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	37 + appendices	N/A

Form DOT F 1700.7 (8-72) **Reproduction of completed page authorized**

ACKNOWLEDGMENT, DISCLAIMER, MANUFACTURERS' NAMES

This publication is based on the results of **ICT-R27-223: Crash Modification Factors (CMFs) for Contrast Pavement Markings on Light-Colored Pavement**. ICT-R27-223 was conducted in cooperation with the Illinois Center for Transportation; the Illinois Department of Transportation; and the U.S. Department of Transportation, Federal Highway Administration.

Members of the Technical Review Panel (TRP) were the following:

- Marshall Metcalf—IDOT, TRP Chair
- Jeffrey Abel—IDOT
- Katherine Beckett—IDOT
- Mark Blankenship—IDOT
- Pat Kenenakhone—IDOT
- Dean Mentjes—FHWA
- Kelly Morse—IDOT
- Thomas Schaefer—IDOT

The contents of this report reflect the view of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Illinois Center for Transportation, the Illinois Department of Transportation, or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

Trademark or manufacturers' names appear in this report only because they are considered essential to the object of this document and do not constitute an endorsement of product by the Federal Highway Administration, the Illinois Department of Transportation, or the Illinois Center for Transportation.

EXECUTIVE SUMMARY

Contrast pavement markings provide improved lane line visibility on light-colored roadways and are commonly used on Portland cement concrete (PCC) sections. There are two common designs currently in use: bordered, where a black edge is placed on both sides of a typically white line, and lead/lag, where a 10-foot contrast strip follows a 10-foot white strip. Contrast pavement markings have been in use for over 15 years and have become more popular in recent years partially driven by autonomous vehicle detection systems. The safety effects of contrast pavement markings are of interest to all departments of transportation (DOTs) and highway agencies; however, the safety effects were unknown at the time of this research. Understanding the safety effects of contrast pavement markings as a crash-prevention countermeasure will add to the pool of engineering knowledge and provide design and operation engineers with a useful tool to reduce crashes on high-speed roadways, where roadway departure crashes (RwD) account for over 50% of fatal crashes. Moreover, the development of a benefit-cost analysis tool that considers crash reductions and cost savings to the economy would provide project decision makers with useful information in the project decision-making process.

To accomplish the goals of the research project, the researchers conducted a literature review focusing on topics related to striping, survey methods, crash modification factor (CMF) development, and economic analysis. A nationwide survey of all DOTs, including key highway agencies that sought feedback regarding the current trends and use of contrast pavement markings, was created and disseminated through an online survey platform. The researchers compiled a database with 1,774 crashes, including key site-specific details for 70 miles of roadway and study sites in six states. Data were analyzed, and CMFs were developed for three roadway designs and three crash severity levels that illustrate contrast pavement marking safety benefits utilizing a quantitative approach.

An extensive literature review determined that no previous studies have evaluated the safety effects of contrast pavement markings. Furthermore, little research has been done on contrast pavement markings; most striping-related research focused on visibility in various conditions with most emphasis on nighttime conditions when roadways are wet. No studies were found that had developed CMFs for contrast pavement markings or conducted any formal safety analysis. Decisions on where to install contrast pavement markings have been qualitative, with the perceived benefit of crash reductions cited as the deciding factor. No previous studies have attempted to perform a before-and-after empirical Bayes (EB) study following methods outlined in the *Highway Safety Improvement Program* (*HSIP*) manual or the *Highway Safety Manual* (*HSM*).

A nationwide survey was developed and disseminated as part of this project, achieving an 88% completion rate. The survey identified current practices by each responding agency, including designs, deployment locations, costs, and other key factors vital to the success of this research project. Bordered and lead/lag designs were found to be nearly equally used, with agencies reporting switching from one style to the other based on qualitative decisions. The survey determined that contrast pavement markings have been in use for over 15 years. The survey identified an increasing trend in recent years and the expansion of lane miles of deployment. At the time of the survey, 75% of responding agencies were using contrast pavement markings in some capacity, with 23% of those that were not using them considering their use. The survey also identified that PCC sections of high-speed roadways are the predominate location for contrast pavement markings and visibility was the leading decision factor for installation. The survey further identified additional agencies to provide data for the analysis portion of this project, adding an additional five states to the data pool.

Crash data were collected on 70 miles of roadway that included three lane configurations: four, six, and eight lanes. The data set contained 1,774 crashes, including fatal, injury, and property damage only (PDO). Crash data were collected in the before and after periods, ranging from one to three years dependent on the installation date of the contrast pavement markings and available data. Key attributes including average annual daily traffic (AADT), segment length, and crash characteristics for each site were collected. CMFs were developed for the three roadway types and three crash severity levels, using a before-and-after EB approach. Findings suggest a reduction in RwD crashes on all roadway types and severity levels. Results for four-lane roadways were limited to total and PDO crashes, because there were no fatal or injury crash types on the limited sections tested, resulting in a CMF of 0.84. CMFs for six-lane roadways were 0.84, 0.93, and 0.87 for total, fatal/injury, and PDO crashes, respectively. Fatal and injury crashes were grouped together because of the lack of fatal crashes and limited number of injury crashes in each severity level. CMFs for eight-lane roadways show the most benefit: 0.71 for total, 0.81 for fatal/injury, and 0.95 for PDO. The findings suggest contrast pavement markings reduce RwD crashes between 5% and 29%. Testing was also conducted between bordered and lead/lag designs to identify if one design provided superior benefit over the other. Statistical analysis via multiple comparison testing did not indicate significant differences between the tested groups, resulting in a p-value of 0.229 higher than the alpha level of 0.05.

Another goal of this project was to develop a benefit-cost analysis tool that could be used to quantify the benefits of contrast pavement markings and to determine if the extra cost of installation is an economical choice. To calculate the validity, standard economic principles were applied using the crash reductions in terms of dollars as a benefit and installation and maintenance as the cost. The cost of each crash severity was applied to the predicted crash reduction utilizing the CMFs developed for this project. The monetized value of crash reductions was found to greatly outweigh the cost of installation and maintenance of contrast pavement markings for all scenarios tested. Benefits of a single crash by type are estimated to be $1,459,479 (fatal), $78,637 (A-injury), $28,761 (B-injury), $16,346 (C-injury), and $709 (PDO) considering the reduction quantified by the CMF and current cost of crashes in 2022. A benefit-cost ratio greater than one is expected when one fatal or one A-injury crash is prevented, or any number of crash combinations that result in a higher savings than installation and maintenance costs, indicating the project is feasible. The benefit-cost analysis tool was designed to require key user inputs that adjust crash costs, benefits, and other monetary values to the analysis year and life expectancy of the project.

Based on the findings, contrast pavement markings are believed to be effective at reducing RwD crashes on the three high-speed roadway configurations tested—four, six, and eight lanes—in urban/suburban areas. They provide crash reductions resulting in economic savings related to crash costs that greatly outweigh the additional cost of contrast pavement markings. The developed benefit-cost analysis tool can be used to support the decision-making process by providing a quantitative analysis in dollars regarding economic savings due to contrast pavement markings.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1: INTRODUCTION

Roadway departure (RwD) crashes are known to be a leading cause of fatal and injury crashes on U.S. roadways. The Federal Highway Administration (FHWA) defines a RwD as a vehicle crossing an edge line, centerline, or otherwise leaving the traveled way (McGee, 2018). The study also found that over 50% of fatal crashes are labeled as RwD crashes. The alarming number of fatalities can be addressed through innovative highway designs and countermeasures. Many countermeasures are available to address RwD crashes that offer varying degrees of prevention or severity reductions. Contrast pavement markings are relatively new when compared to traditional countermeasures such as rumble strips, increased clear zones, and curve improvements. The listed countermeasures have been widely studied; however, at the time of this research, there were no known studies regarding contrast pavement markings and their safety benefits.

PROBLEM STATEMENT

Contrast pavement markings are believed to provide superior guidance and delineation for motorists in a variety of light and climatic conditions; unfortunately, there has been very little research to support this claim. Without the support of evidence-based research, highway departments are unable to justify the added expense of installing contrast pavement markings.

Before any quantitative data analysis can begin, reliable data needs to be collected. A preliminary literature review seeking to identify crash modification factors (CMFs) for contrast pavement markings on light-colored pavement was conducted and did not identify any research that had quantified the safety benefits. Using Transportation Research Board's TRID database, similar studies were identified that conducted research on pavement markings and other related safety measures that offer guidance in developing quality CMFs. Therefore, a significant part of this research project was to conduct a thorough literature review and a national survey of departments of transportation (DOTs) to develop an understanding regarding the current use and impact of contrast pavement markings realized by other agencies. Based on the quality and quantity of data collected, the research project moved into the analysis phase and the development of CMFs for contrast pavement markings.

RESEARCH OBJECTIVE

The goal of this research project was to develop CMFs for the use of contrast pavement markings on light-colored pavement. To attain this goal, the project had four objectives:

1. Convene a Technical Review Panel (TRP) made up of roadway safety specialists from DOTs and non-DOTs who provided counsel to the research project.

2. Gather the most up-to-date information regarding contrast pavement markings by doing a thorough literature review and conducting a nationwide survey of all state DOTs and other non-DOTs having jurisdiction over roadways.

3. Quantify crash data to determine CMFs using appropriate statistical approaches based on the quantity and quality of data obtained.

4. Develop a benefit-cost analysis tool to assist decision makers in future roadway planning projects.

RESEARCH APPROACH

The proposed research addresses the following tasks and required deliverables.

Task 1—Evaluation of Illinois Department of Transportation (IDOT) Crash Data and Survey of Other Jurisdictions

To begin the project, an extensive literature review was conducted that sought to identify DOT practices on pavement striping focused on contrast pavement markings on light-colored pavement. The literature review expanded on the current knowledge of the researchers and relied heavily on Transportation Research Board's TRID database.

A survey was developed and sent to each state DOT and other highway agencies seeking further insight into the current state of practice or recent developments regarding pavement marking types. The survey focused on safety aspects associated with different pavement marking types and any crash analysis that has been completed by each agency surveyed. To ensure the highest possible participation, follow-up phone calls were placed to each agency contact asking for completion of the survey and discussing potential safety benefits of the study. The survey also sought to identify if studies on similar topics are currently underway. A goal of the survey was to identify any quantifiable safety benefit that has not been published or that has not been identified in the literature review through the available databases. The survey also sought additional locations and databases that could be included in the analysis to improve the sample size and increase the reliability of the statistical analysis.

Task 2—Statistical Study

A statistical approach was taken to develop the desired CMF, utilizing statistical software capable of regression modeling. A common problem encountered when developing CMFs is having too few data points to conduct a typical before-and-after study that will yield statistically significant results. A common approach when data are limited due to too few implementation sites or few crashes is to adopt an empirical Bayes (EB) approach utilizing observational before–after study techniques. Using this method, a previously developed statistical prediction model that had independent variables unique to Illinois' roadways was used. The two factors known to have the greatest impact on prediction models are average annual daily traffic (AADT) and segment length. Data for each site were collected to more accurately predict crash expectancy.

The number of lanes, lane width, and other roadway geometric design features are also known to influence safety but were controlled by using similar locations. This method eliminated the effect of other geometric designs that are also known to effect roadway safety and improved the study's results.

Task 3—Development of a Crash Modification Factor

The development of a CMF was dependent on the quality and quantity of the available crash data. Dependent on data, CMFs can be developed that quantify the change of different crash severities, different roadway designs, different crash types, and any other desired factor of interest.

The preferred method of the researchers was to use an EB approach. This approach requires an extensive data set for the development of statistical prediction models (Gross et al., 2010). Previously developed prediction models were used to estimate the effect of the contrast pavement marking on light-colored pavement. The ideal data set should include multiple locations where the new pavement markings have been implemented on similar roadways to eliminate the effects of roadway geometrics, allowing the researchers to focus on the desired roadway change. While time periods of three or more years are typically desired in the before and after period, they are not always possible when studying new countermeasures. An implementation period of less time can yield quantifiable results or provide an estimate of the effects of some design change. If too few locations are available to develop a statistically significant prediction model, then the EB method is not recommended.

Alternative methods were considered to develop CMFs if the data were too limited or if too few locations were available. A before–after study with comparison sites is an ideal and simple method when few locations are available to study (Gross et al., 2010). Several CMFs developed for use with the *Highway Safety Manual* (AASHTO, 2010) use this approach and are included on the Crash Modification Factors Clearinghouse website (FHWA, 2019). For the before–after approach, data would be analyzed at the implementation sites as well as a similar non-treatment site for control over regression to the mean bias, which could inflate or deflate the true effect of the contrast pavement markings. An additional alternative method that could be used is a cross-sectional study (Gross et al., 2010). This method can be used if before-treatment data are not available to conduct a before–after study or if data sets in the before period do not have enough details to make a comprehensive comparison. The cross-sectional method compares similar sites with preferably the only difference in roadways being the factor being studied, in this case the contrast pavement markings. With the cross-sectional approach, multiple variable regression models are developed and used to estimate the effect the implemented change has on roadway safety, with the predominate factor typically being traffic volumes and the change being studied. Other factors, including roadway geometrics, can be analyzed if differences are found between locations. However, it is rare for geometric differences to have a significant effect on the model's outcome.

The ideal situation would be that the literature review or survey reveal existing CMFs or data that can be used from other DOTs and non-DOT sources to develop localized CMFs. With this approach, a metadata analysis (Gross et al., 2010) would be suitable, where results from other studies would be included in the development of the CMFs and evaluated based on their development method. The results would be adjusted using a weighted average to correct for the effect of the methodology used.

Regardless of the approach taken to develop CMFs, a benefit-cost analysis tool can be developed to assist decision makers when seeking to improve the safety of roadways following methodologies approved by the Crash Modification Factors Clearinghouse and used in conjunction with the *Highway Safety Manual*.

Task 4—Final Report

Anticipated Research Results

The anticipated research results and deliverables for this project included the development of CMFs for contrast pavement markings on light-colored pavement and the development of a benefit-cost analysis tool. The desired results were developing CMFs for different crash types, crash severity levels, and for different roadway geometric designs using data from IDOT with the inclusion of data from other sources where available.

Expected Implementable Outcome(s)

The anticipated research results support IDOT's goal of establishing a benefit-cost analysis for installing contrast pavement markings on light-colored pavement that can be used in the decision-making process for pavement marking selection and the disbursement of safety funding. The expected reduction in crash types impacted by the pavement marking change were also identified to help drive the fatal crash totals toward zero in Illinois.

CHAPTER 2: LITERATURE REVIEW

Previous studies related to pavement marking designs, survey methods, CMF development, and economic analysis were reviewed. This chapter summarizes an extensive literature review that covered topics related to the project. No previous studies were identified that quantified the safety effects of contrast pavement markings.

PAVEMENT MARKING DESIGNS

Past studies have been conducted that focused on the ability of drivers to see pavement markings in various conditions including day versus night, wet versus dry, and exposure to the elements. The reviews identified research in marking type, width, and contrast.

The safety effects of retroreflective pavement markings have been well studied over the past several years (Varghese & Shankar, 2007; Omranian et al., 2018; Traffic & Transit, 2022). A study by Texas A&M found that nighttime crashes account for a disproportionate amount of the total crashes on roadways, with rain increasing the risk of a crash by 57% (Traffic & Transit, 2022). A recent study in Michigan focused on the need to provide drivers with pavement markings that were visible regardless of the time of day or weather condition (Pike & Barrette, 2020). The study identified the minimum level of retroflectivity needed to provide adequate luminance during wet conditions on roadways for the driver group tested. The minimum level was found to be 50 million candelas per square meter per lux (mcd/m^2/lux). A survey conducted by the Minnesota Department of Transportation focused on a driver's ability to identify lanes under various conditions (Pike & Barrette, 2020). The results indicated that drivers feel they have little issue seeing the pavement markings to identify lanes during daylight hours; however, nighttime hours caused issues for many drivers. Survey results indicated that 33% of drivers feel they have difficulties seeing lane markings at night, with 66% of the surveyed drivers having problems identifying lane markings in wet conditions during nighttime hours. A study by the Ohio Department of Transportation also found that drivers have the most difficulty identifying lanes in wet nighttime conditions (Abbas, 2011). The Ohio study evaluated three types of pavement markings. All markings offered desirable delineation in daytime dry conditions; however, all three types lost retroreflectivity in wet conditions after the first winter. The decline in retroreflectivity was believed to be a result of snowplow damage during snow removal.

Wider pavement markings of 6 inches have been found to increase visibility over standard 4-inch markings. The benefits have been reported by both human vision and autonomous vehicle detection systems (Gates & Hawkins, 2002; Pike & Carlson, 2018). Wider pavement markings are included in the *Manual of Low Cost Local Road Safety Solutions* (Furnas et al., 2008) produced by the American Traffic Safety Services Association. A survey of DOTs found that 58% are using wider pavement markings to improve visibility and decrease crashes on roadways, targeting fatal and injury crash types at key locations—typically high-speed roadways.

The literature review (Neemann, 2013; TxDOT, 2004; Ceifetz et al., 2017) also found that there are two common designs of contrast pavement markings currently in use. The first type is a lead/lag configuration, where a contrasting black strip leads or follows a white strip. The second common design consists of a white strip bordered with a black strip. Various types of materials are being used, the most common of which are paints and tapes. Examples of lead/lag and bordered contrast strips are shown in Figures 1 and 2, respectively.

Figure 1. Image. Lead/lag contrast strip.

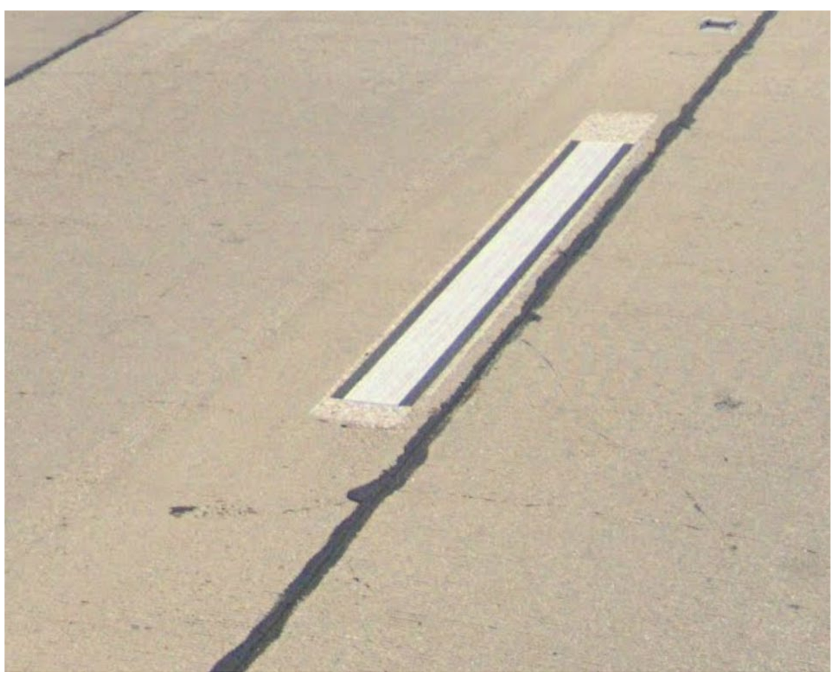

Figure 2. Image. Bordered contrast strip.

SURVEY METHODS

To improve survey responses, a literature review was conducted on past surveys' deployed techniques with a focus on DOTs. Survey methods for collecting information related to transportation projects tend to have low response rates, with 10% being typical. Common methods for improving survey response rates were found to include cold calling respondents, asking them to complete the survey, identifying key personnel to contact so the appropriate personal receive the survey, and limiting the number of surveyed questions to prevent survey fatigue (Gates & Hawkins, 2002; Migletz et al., 1994; Dougald, 2010). Based on recommendations found during the literature review, a strategy was developed for survey creation.

CRASH MODIFICATION FACTORS

CMFs are a useful tool that allow engineers to design safer roadways and can be used in the decision-making process to quantify the benefits that can be expected by some design change, typically in terms of reduced crashes. The current body of engineering knowledge does not included CMFs for contrast pavement markings but does provide insight into the proper development of quality CMFs through various approaches.

There has been much research on quantifying the safety impacts of changes to pavement markings in the form of CMFs, with most studies following the FHWA guide (Gross et al., 2010) for developing quality CMFs. Previously developed CMFs can be used in conjunction with the *Highway Safety Manual* (*HSM*) to provide safer roadways. The *HSM* provides guidance on the appropriate method of conducting a safety analysis on a roadway, which is further illustrated in the *Highway Safety Improvement Program* manual (AASHTO, 2010; Herbel et al., 2010).

BENEFIT-COST ANALYSIS

A benefit-cost analysis compares the benefits and costs associated with some treatment over the expected life for the purpose of justifying the spending of funds. A benefit-cost analysis is typically used to compare multiple designs, with the highest benefit-cost ratio being the most economical choice. A benefit-cost analysis can also be used to decide whether to apply a treatment when a single option is evaluated. If the benefit-cost ratio is greater than one, a favorable decision can be made to apply a treatment.

FHWA recently published the *Highway Safety Benefit-Cost Analysis Guide* (Lawrence et al., 2018) to help transportation agencies make informed decisions related to transportation projects. The document gives guidance on identifying the costs of projects as well as the direct and indirect safety benefits that can be realized. Benefits may include crash reductions, reduction in delays/travel times, reduced fuel consumption, and emissions. Project costs and direct benefits are typically easy to quantify, but other costs can be difficult to quantify. The document also provides procedures to estimate the cost associated with travel time and emissions, which are not typically used as a deciding factor, as their dollar contribution is low when compared to the safety benefits of crash reductions. Another important aspect identified during the literature review was the need to adjust costs and benefits to present values.

SUMMARY

The literature review identified past studies that have quantified the effect of wider pavement markings and other ways of improving visibility in targeted lighting conditions. No past research was identified that focused on contrast pavement markings. Literature was also reviewed that focused on survey methods that provided a guide to disseminating a survey with increased responses. Methods for the development of CMFs through quantifiable methods were also identified, and methods for combining multiple studies were reviewed. Methods for assigning a value to a crash were evaluated at the national level, and methods for adjusting dollars for current year and location were identified. Benefit-cost methods used in past studies were evaluated with key information identified that will guide the analysis. Overall, the literature review identified key information to guide the analysis portion for this study.

CHAPTER 3: NATIONAL SURVEY

A national survey was conducted to gather information regarding the current use of contrast pavement markings by DOTs and highway agencies. The survey targeted information that would be helpful in the research analysis. Chapter 3 presents the survey development, deployment methods, analysis of results, and conclusions at the national level.

SURVEY DEVELOPMENT

During the spring of 2021, the researchers drafted survey questions and presented the draft questions to the TRP members. The TRP members provided input, and the researchers modified and added the questions to ensure the survey would provide sufficient information to assist the research project. The final survey questions were sent to the TRP members through a survey software link for additional feedback on the survey from a user perspective. During a project meeting in late spring, feedback was provided on the survey software structure. Additional adjustments were made, including providing an estimated time to complete the survey and a tracking bar showing percent completed. A copy of the survey questionnaire is included in Appendix A, which shows how the questions were structured. Questions were structured to obtain valuable input from participating agencies. Follow-up questions changed based on participants' responses. For example, if participants reported not using contrast striping, then they were directed to a question asking if they were considering using contrast striping.

DEPLOYMENT METHODS

The survey was released in May 2021 and remained active until August 2021. Contact information had been obtained before deployment so that striping engineers at the national level could be targeted. Surveys were sent via email to the targeted list of DOT and highway agency engineers, including all state DOTs and highway agencies with substantial miles of limited access roadways. To boost the response rate, reminder emails were sent out after the first month providing an update on the current response rate. The first month response rate reached 50%. Cold calling the targeted list was conducted as a last attempt to boost the response rate before the end of the survey, resulting in an additional 10% in responses in the last week before the close of the survey. Using the targeted method for deployment, a high return was realized with 44 states responding, resulting in an 88% response rate. A state was counted as responding if at least one response was received. Responses came from individual districts or central offices of DOTs. Figure 3 depicts the states that completed the survey in red, with nonresponding states shown in white.

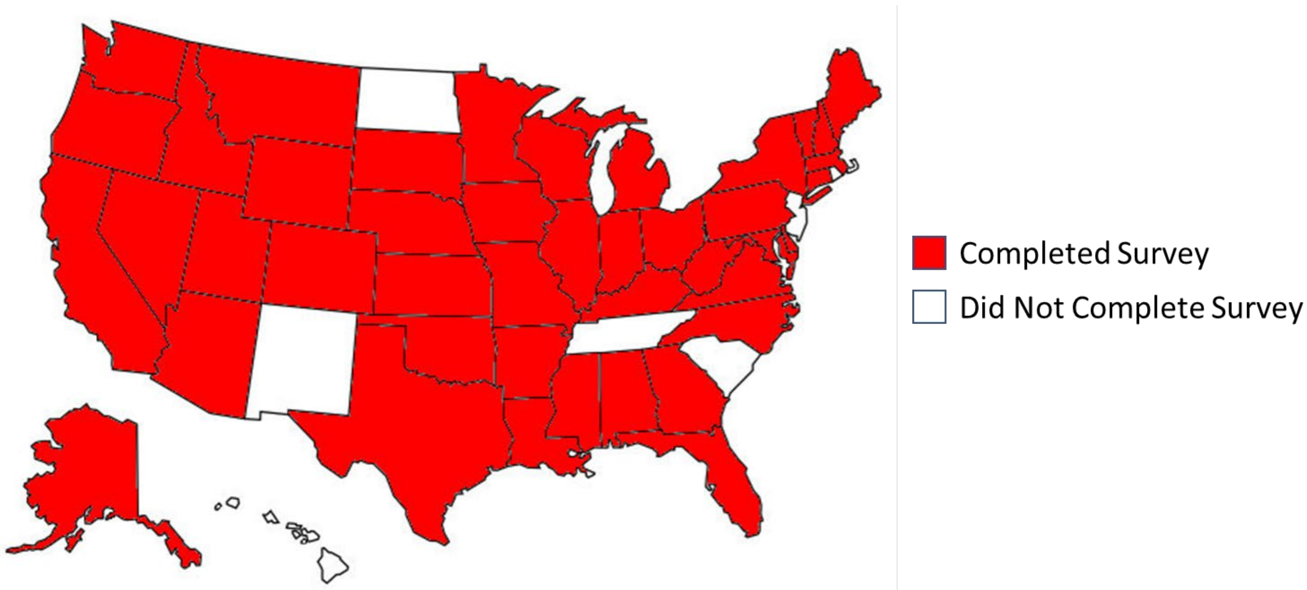

Figure 3. Image. States that completed the national survey.

RESULT ANALYSIS

The first part of the survey identified the percentage of responding agencies that were using contrast pavement markings in some capacity and the marking design being used. Agencies' responses show that 75% are currently using contrast pavement markings in some capacity. Marking configuration was also identified with 45% using bordered, 40% using lead/lag, and the remaining 15% using some combination of lead/lag and bordered designs. Of the 25% of agencies not currently using contrast pavement markings, 23% are considering their use in the future. Further questioning sought the reason for implementing contrast pavement markings. Results indicated that most agencies adopted the use for perceived safety benefits and perceived traffic flow improvements. Results from these questions can be seen in Figures 4 to 7.

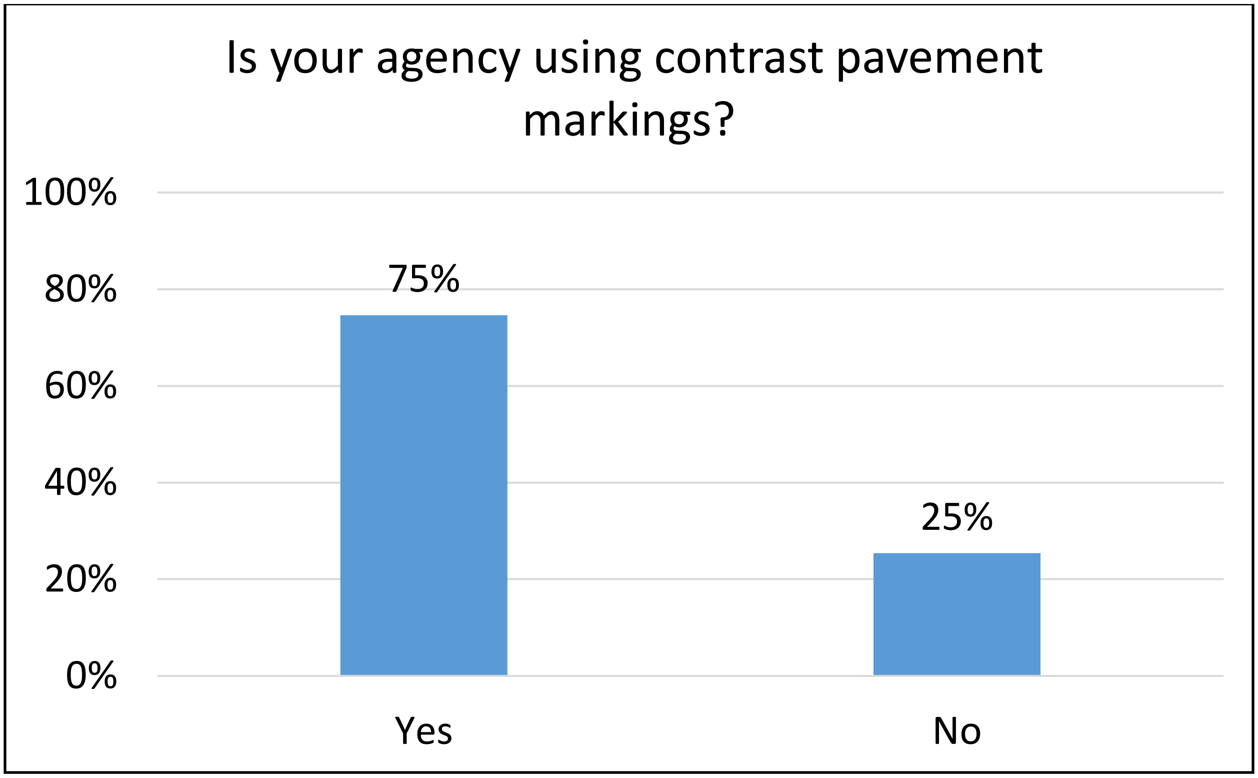

Figure 4. Graph. Agencies using contrast pavement markings.

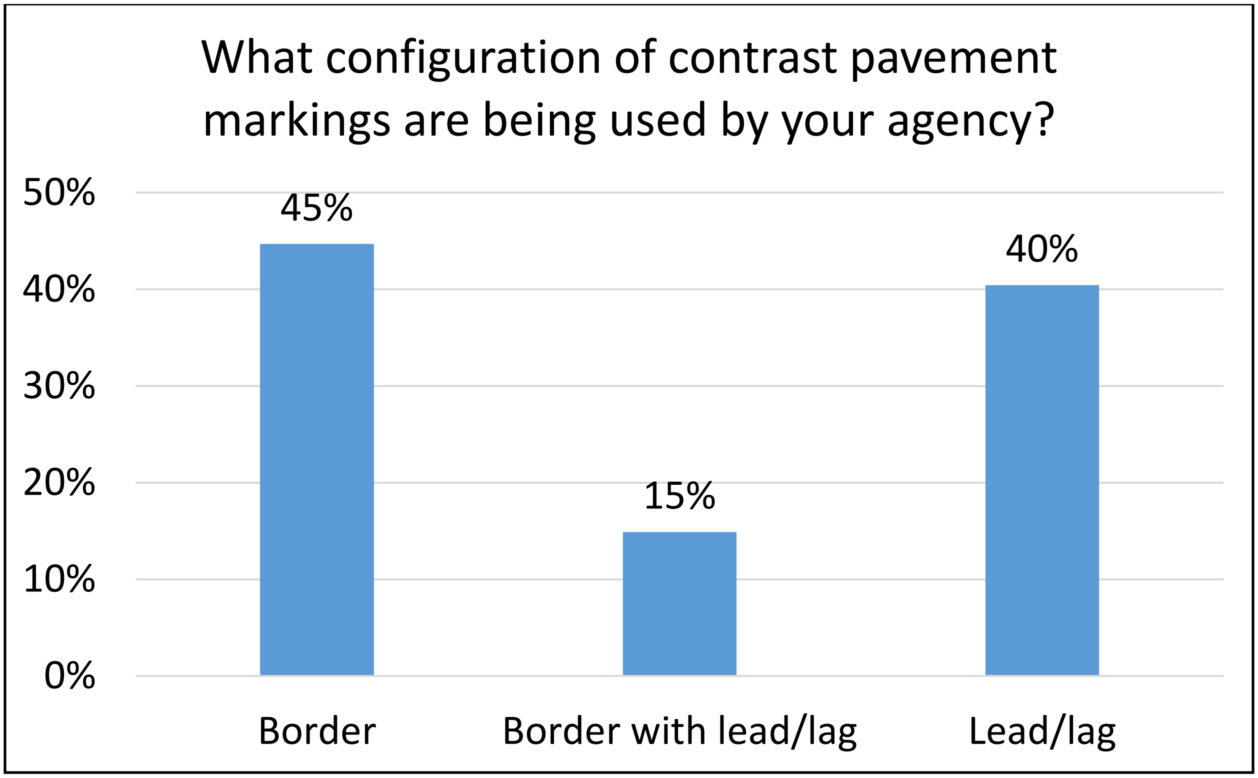

Figure 5. Graph. Contrast marking design types.

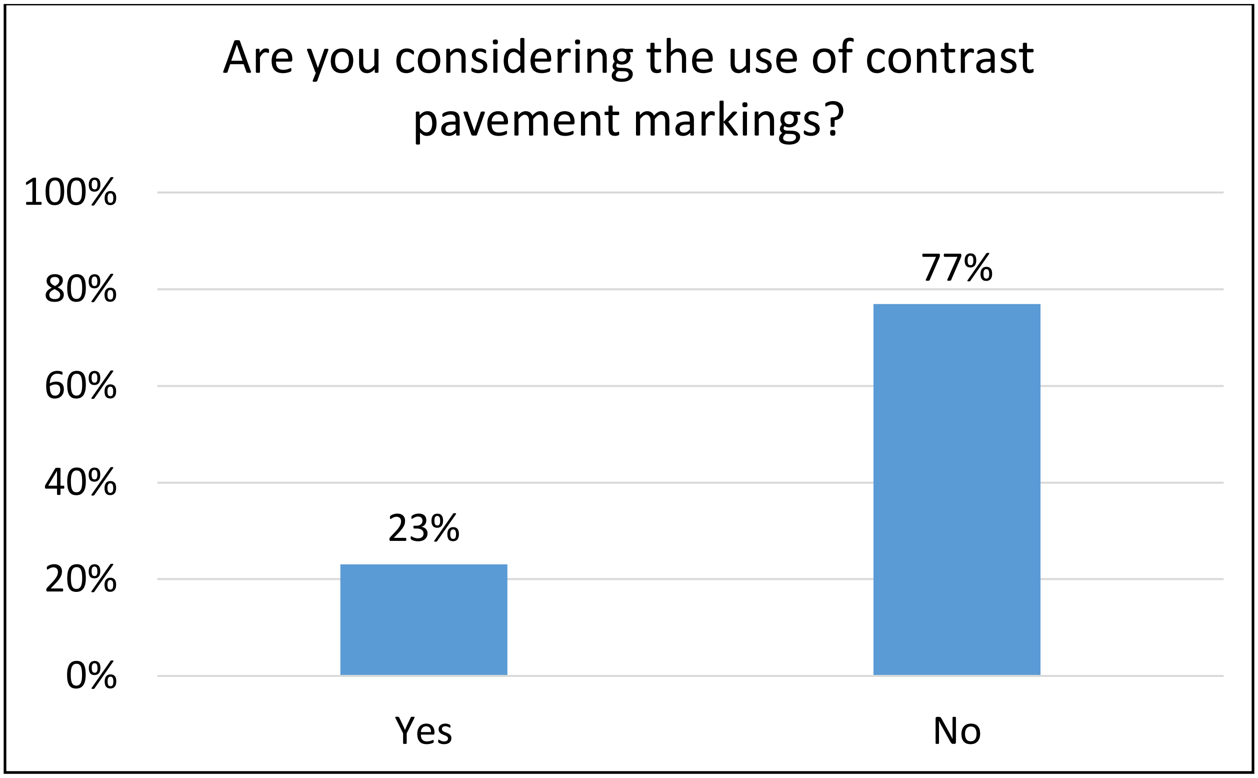

Figure 6. Graph. Percent of agencies considering contrast pavement-marking use.

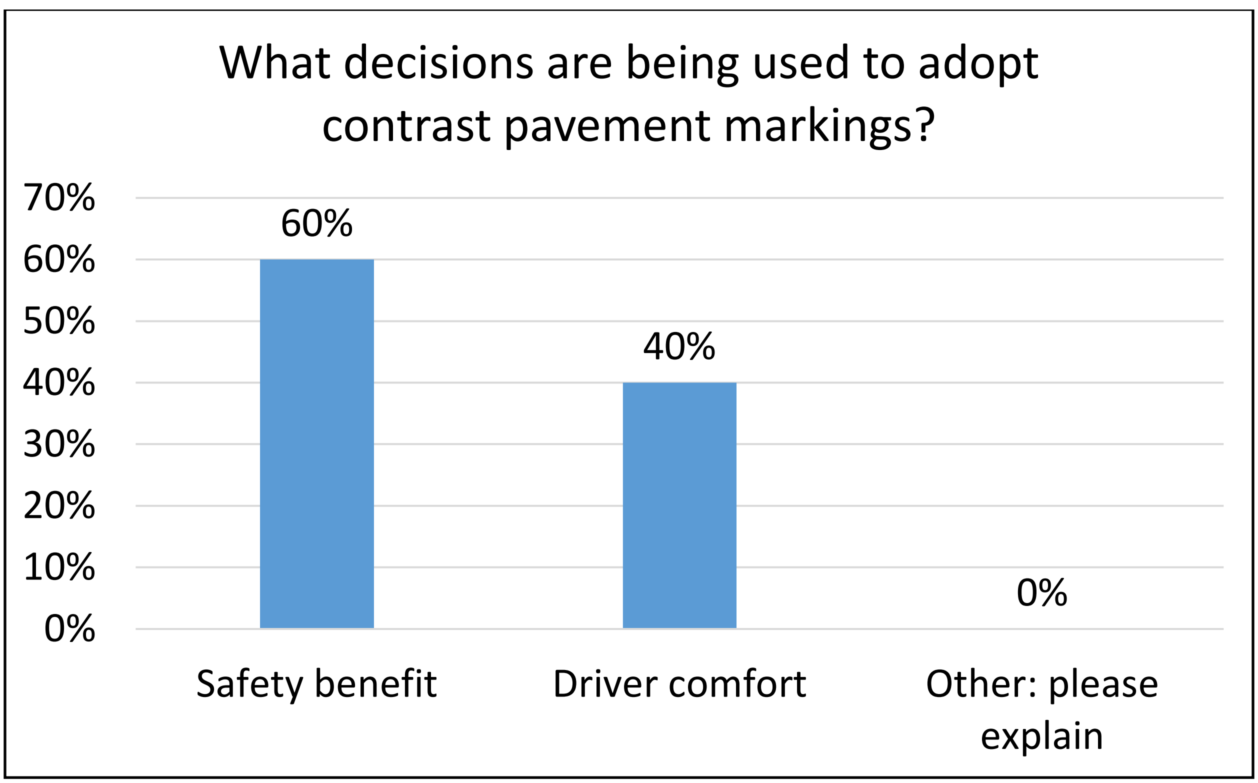

Figure 7. Graph. Contrast pavement marking decision factors.

Additional questions asked participants the roadway surface type, roadway type, and what benefits had been realized after installing contrast pavement markings. Responses indicated that most agencies (77%) had installed contrast pavement markings on Portland cement concrete (PCC) due to its lighter color, which can closely match the white strip and make it difficult for drivers to identify lanes. Few agencies (2%) reported using contrast striping on hot-mix asphalt. Where deployed on hot-mix asphalt, these sections were reported to be sun bleached, producing a lighter color that closely matches the white strip. Agencies reported that contrast markings were only installed on hot-mix asphalt if the pavement life expectancy was greater than or equal to the striping life, commonly five years. The survey responses to pavement type deployment can be seen in Figure 8.

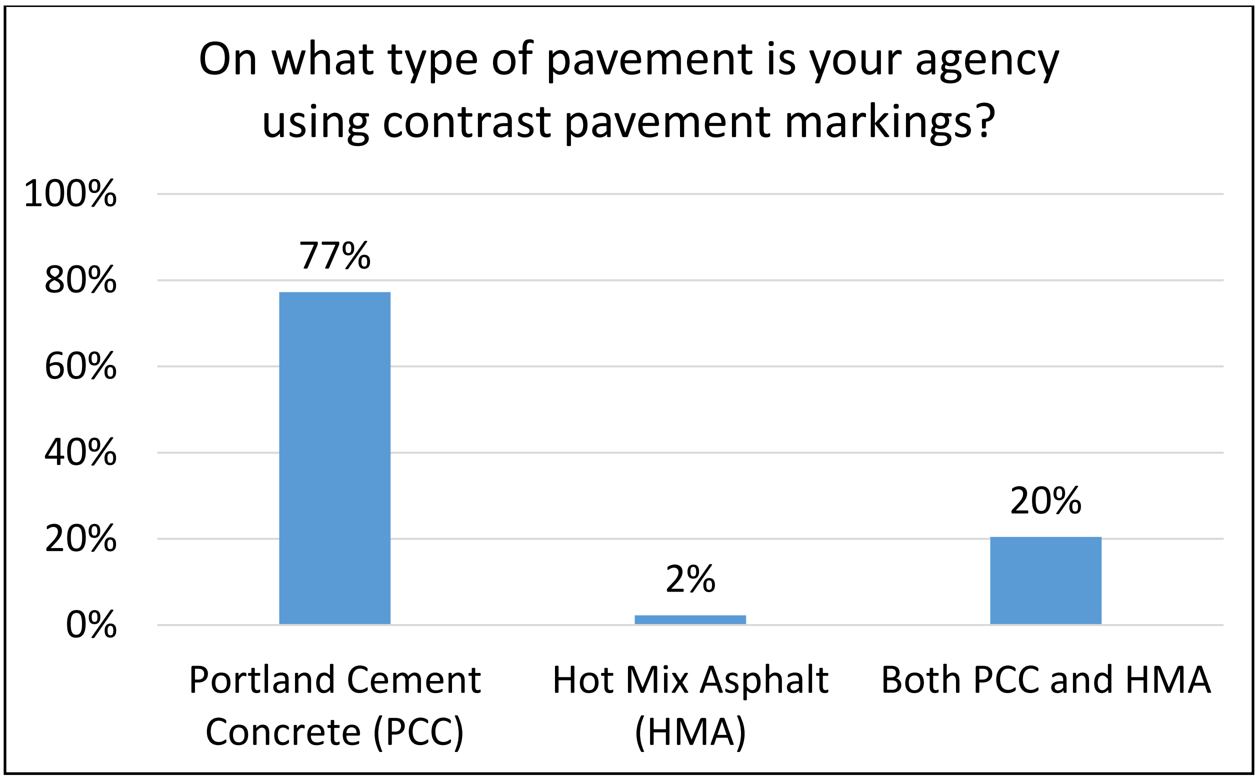

Figure 8. Graph. Pavement types where contrast markings are used.

A follow-up question asked respondents the class of roadway on which contrast pavement markings were being used. Agencies reported that contrast pavement markings are predominantly installed on high-speed roadways such as interstates and freeways, accounting for 55% of their use. The second highest use was found to be on highways, which accounted for 32% of their use. Few local roads were reported to have contrast pavement markings, accounting for only 4% of their use. Some agencies reported use on other types of roadways, accounting for 8% of contrast pavement markings' use. However, after examining the explanations provided by respondents, it was determined that most of the 8% were toll roads, a high-speed roadway similar in class to interstates and freeways. Figure 9 presents the results.

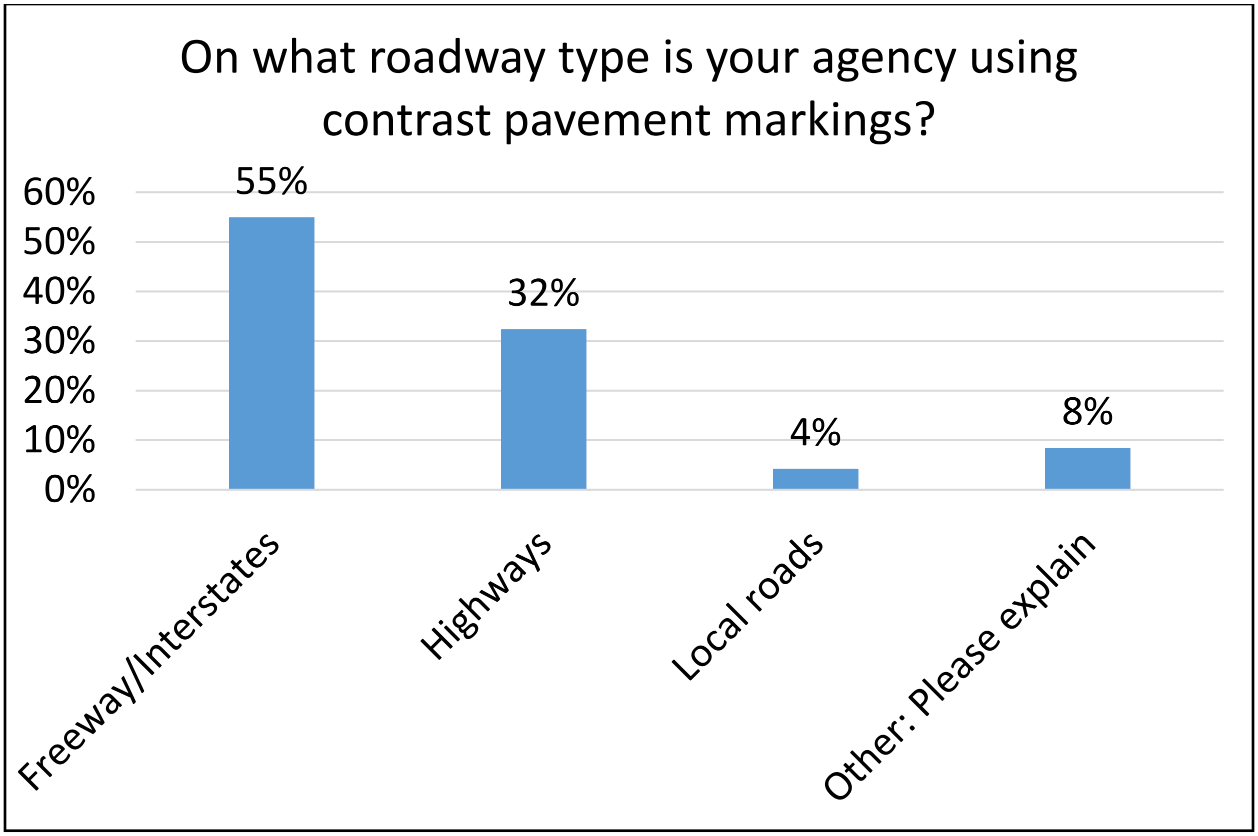

Figure 9. Graph. Roadway types where contrast markings are used.

Agencies that reported using contrast pavement markings were asked how they made the decision to implement them. Based on the responses, the decisions appeared to be speculative in that no data were used to make a quantitative decision. Perceived crash reductions and traffic flow improvements accounted for 20% and 23%, respectively, of the decision making, with the additional 57% falling into the “other” category. Responses that indicated “other” received a follow-up question that sought direct input. The overall responses from the follow-up question were reviewed and fell into two main categories—autonomous vehicles and visibility—accounting for 22% and 78%, respectively. Results can be seen in Figures 10 and 11, where responses from the follow-up question have been summarized into two list categories.

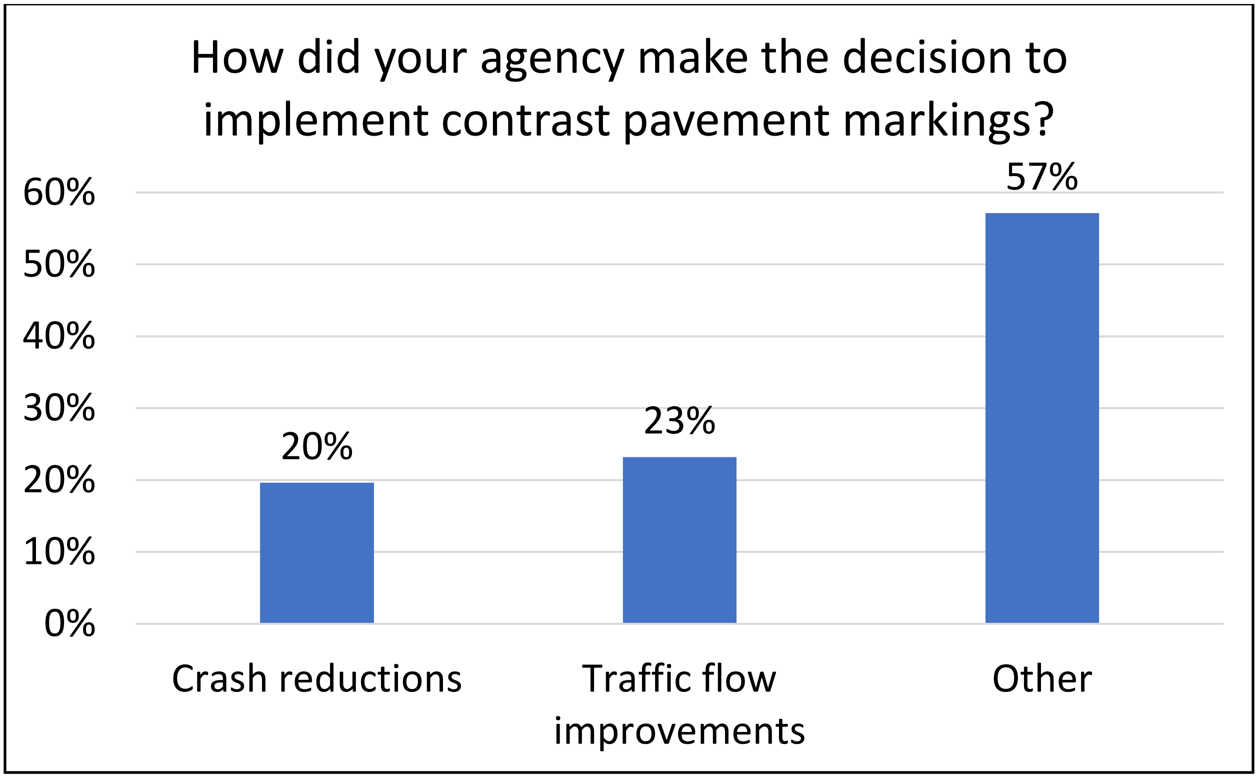

Figure 10. Graph. Agency decision implementation.

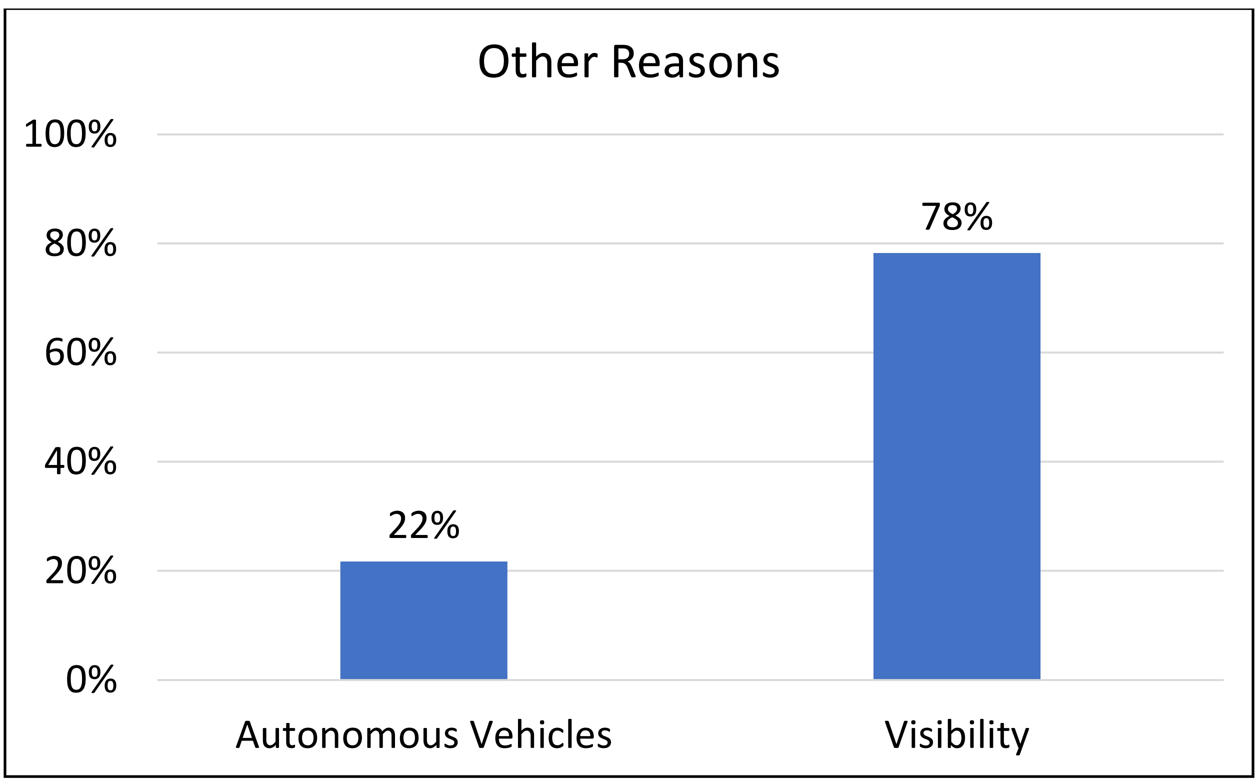

Figure 11. Graph. Agency decision for other explanations.

Contrast pavement markings are relatively new in Illinois, so it was desired to have an understanding of the length of time other agencies have been using them. A question was constructed that grouped years of use into six categories. Of the agencies using contrast markings, most have been using them between 6 and 15 years, accounting for 52% of the responses. Some agencies reported using contrast pavement markings for more than 15 years (19%). The remaining 29% of the responses fell into the 1 to 5 year categories. It was evident that agencies are expanding the use of contrast pavement markings, many in response to autonomous vehicle technologies. Detailed results of each category can be seen in Figure 12.

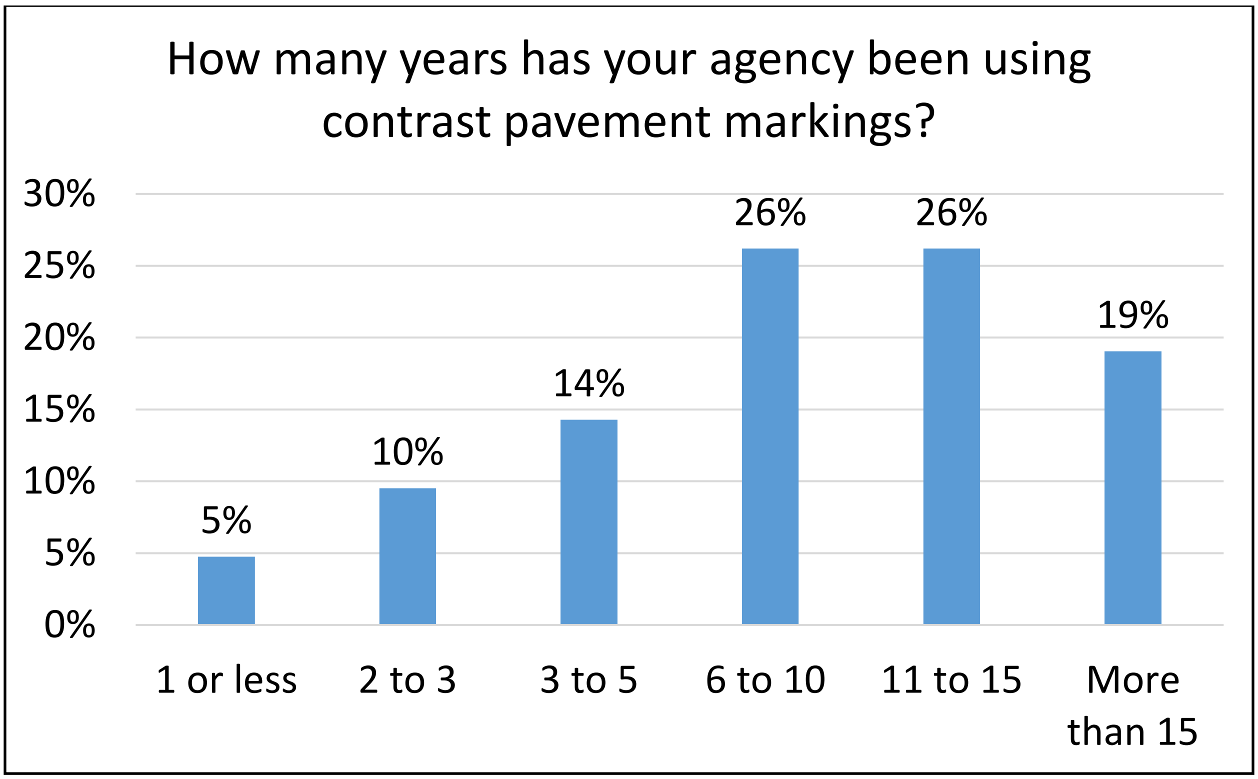

Figure 12. Graph. Years of contrast pavement marking use by agencies.

Agencies that reported using contrast pavement markings were also asked what benefits had been realized in the form of crash reductions, driver comfort, or if some other benefit had been identified. Only 10% of agencies reported a reduction in crashes after installing contrast pavement markings. The crash-reduction benefit was by observation only, as no agency reported a quantitative analysis with crash data after installing contrast pavement markings. Most agencies reported an improvement in driver comfort in that drivers were able to better identify their lane of travel, reducing driving stressors, a common goal of DOTs. The “other” category accounted for 37% of the responses, with the majority of feedback indicating improvements in visibility after the installation of contrast pavement markings, also linked to driver comfort. Results can be seen in Figures 13 and 14.

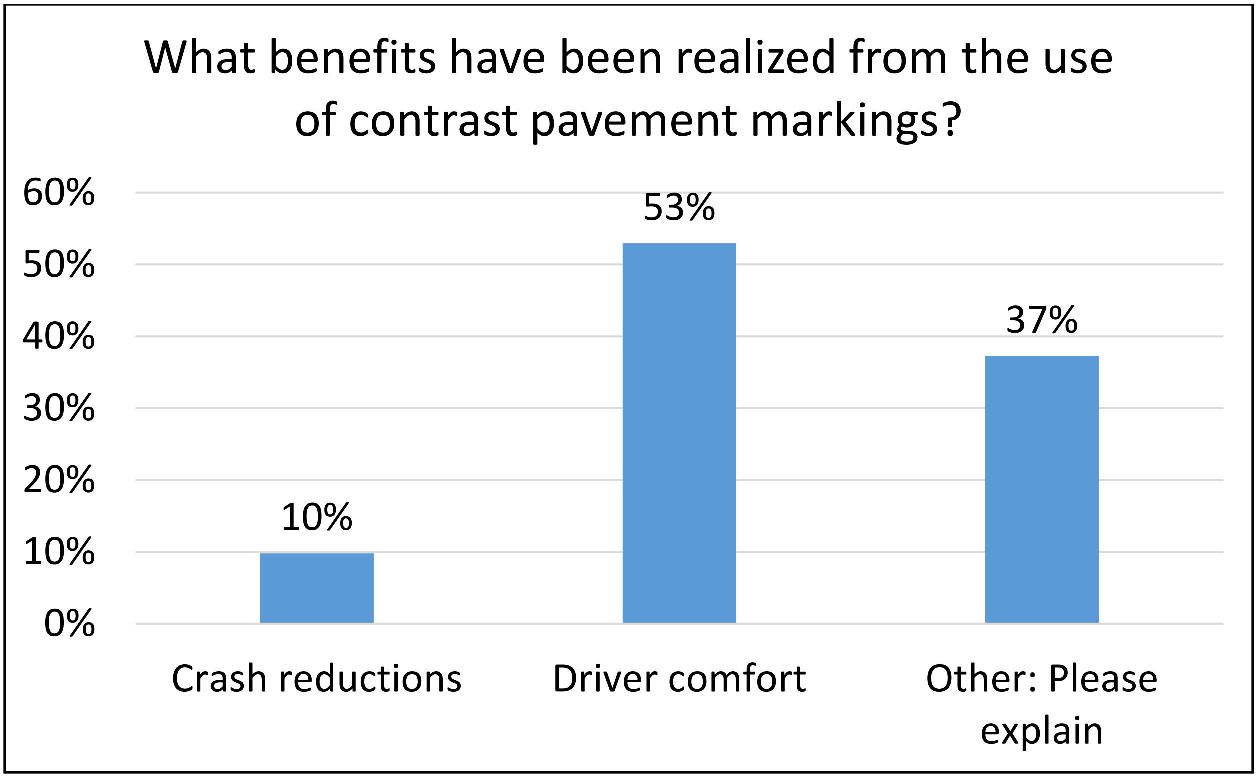

Figure 13. Graph. Reported benefits of contrast pavement markings.

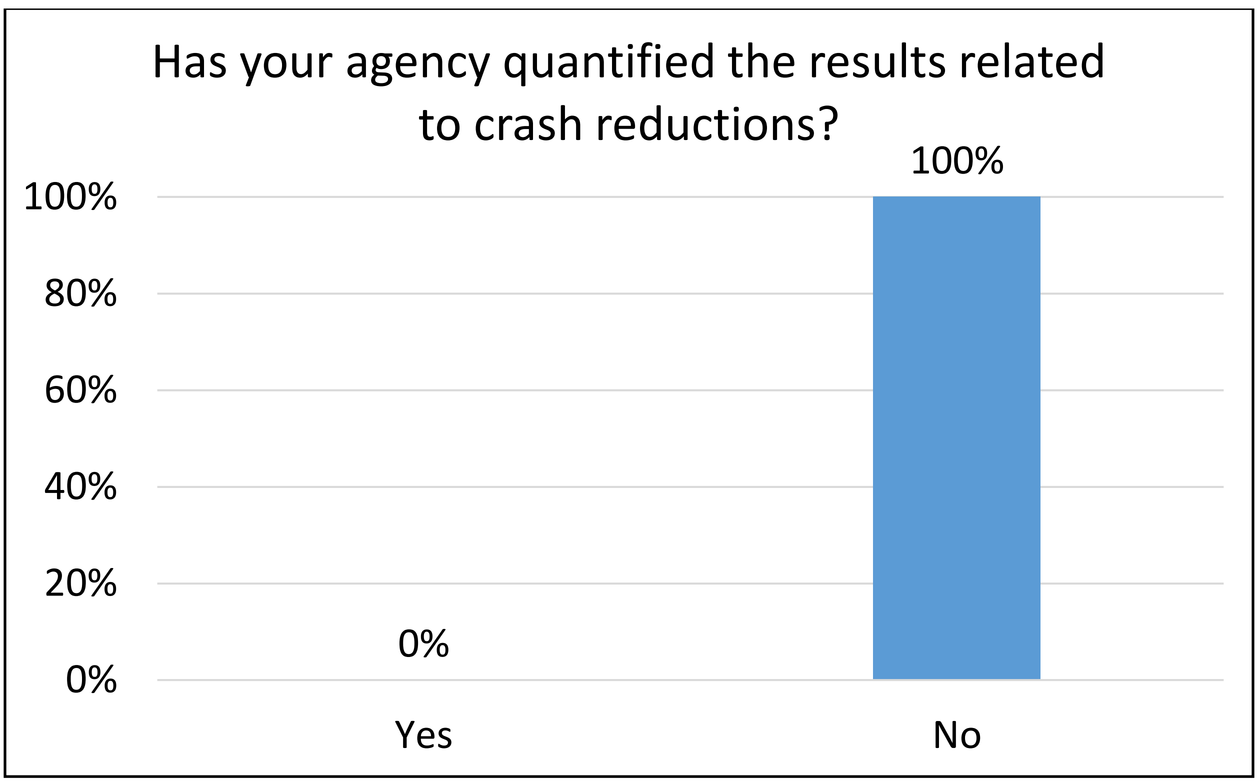

Figure 14. Graph. Agencies who have quantified crash reductions.

Questions seeking to identify the cost effectiveness of contrast pavement markings were asked. Most agencies reported that contrast markings had been found to be cost effective. Agencies had taken the life span of the markings and installation costs versus other methods—including paint, which may require more frequent maintenance—into consideration. The cost to install per lane foot was also sought through a follow-up question. The question included the cost of grooving to prevent snowplow damage to striping, a practice common in states that experience snow during winter months. Most agencies reported a cost between five and seven dollars per lane foot when grooving was used with tapes. States that did not use groove markings reported installation costs at two dollars or less per lane foot. However, the materials used were typically paints. The results from the questions can be seen in Figures 15 and 16.

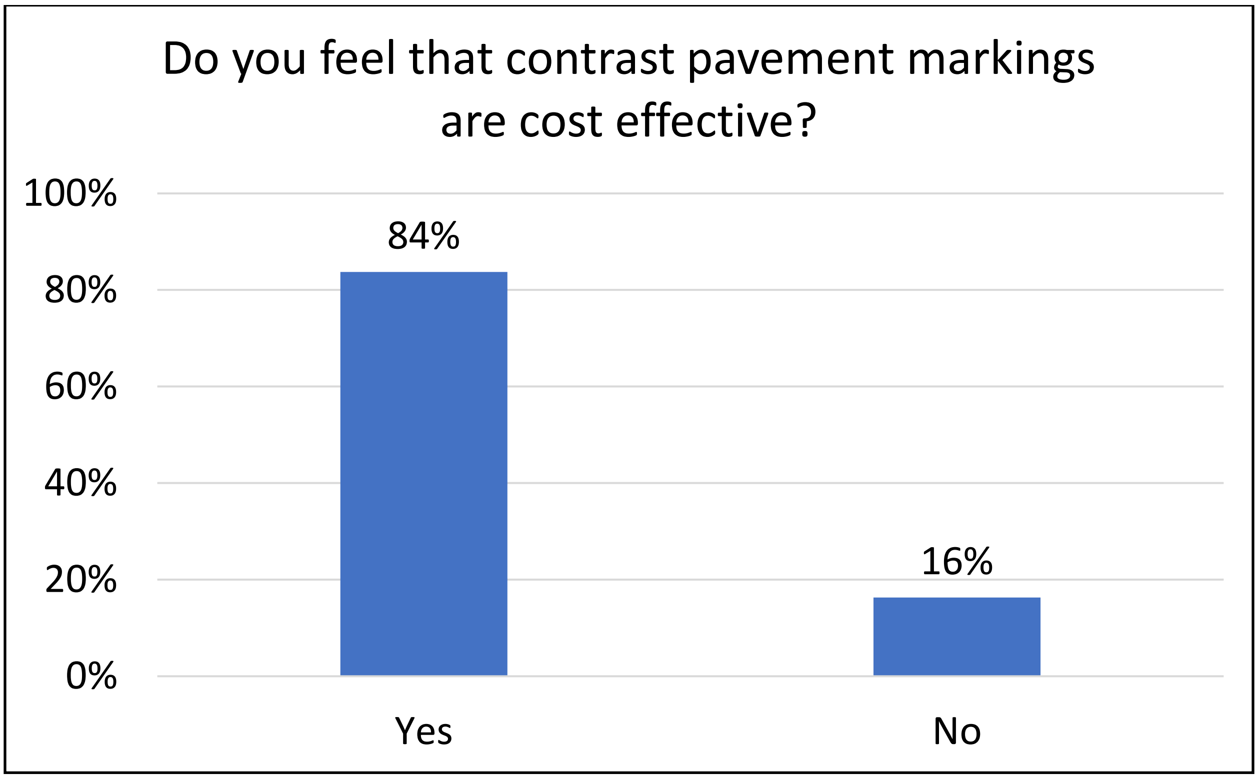

Figure 15. Graph. Agency reported cost effectiveness.

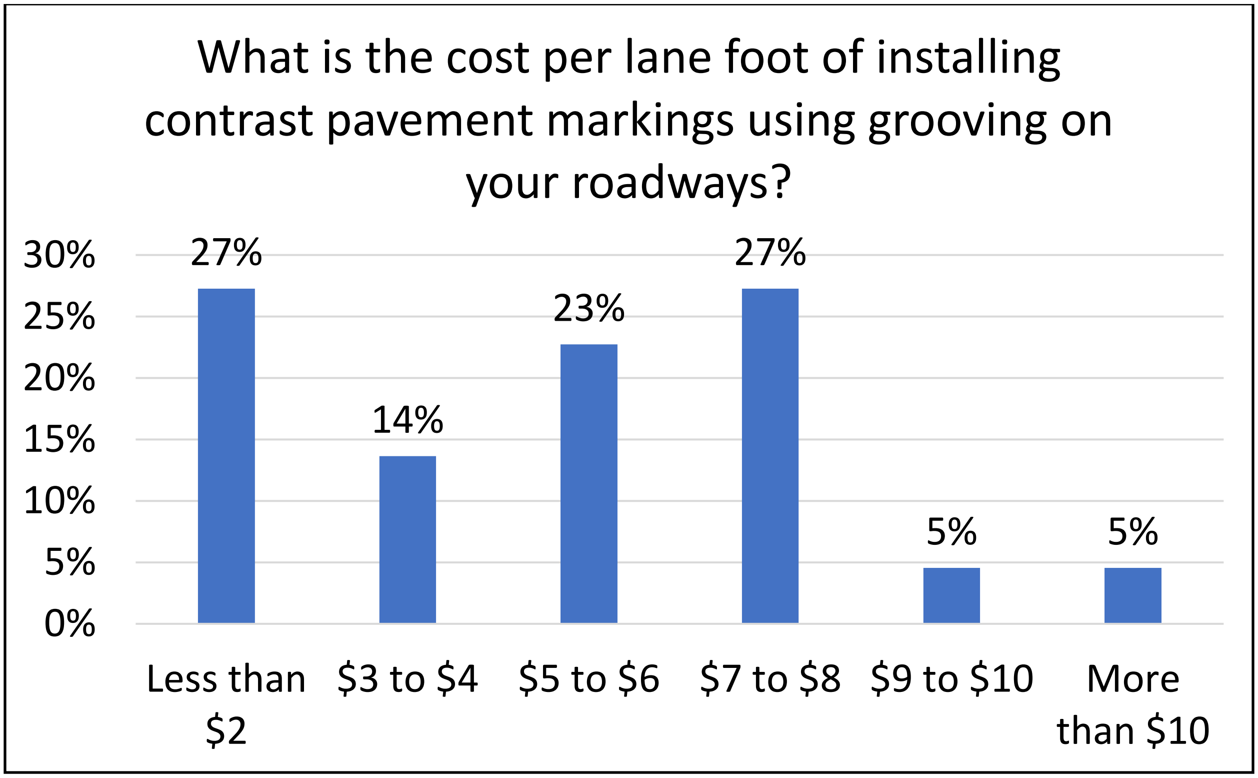

Figure 16. Graph. Cost per lane foot to install.

Illinois had limited study sites for contrast pavement markings. To increase the sample size of the study, all responding agencies were asked to provide data and locations for an expanded analysis. Of the responding agencies who had installed contrast pavement markings, 15% were willing to provide locational information and/or crash data. Upon follow-up interviews with each agency, it was determined that several agencies did not have adequate data due to installation taking place within the last few years, which limited the analysis period. After the interviews, five additional states were included in the analysis that had data available for two to three years before and after installation. Results from the questions can be seen in Figures 17 and 18.

SUMMARY OF SURVEY FINDINGS

The overall survey findings provide a good view of contrast pavement marking use at the national level. Many agencies have been using contrast striping on roadways for many years. Contrast striping was mainly used on PCC sections, which are commonly bridge decks that are short in length (i.e., 0.10 miles). No quantitative analysis focusing on the safety benefits of contrast pavement markings was identified through the national survey. However, perceived benefits were identified mainly in the form of improved visibility translated to improved driver comfort. Most responding agencies reported similar cost of installation in the five-to-eight-dollar range when grooving of striping was required. Five additional states were identified to contribute data to the analysis. Overall, the survey provided a good picture of the national trends in contrast pavement markings. Appendix B presents raw example responses from key questions.

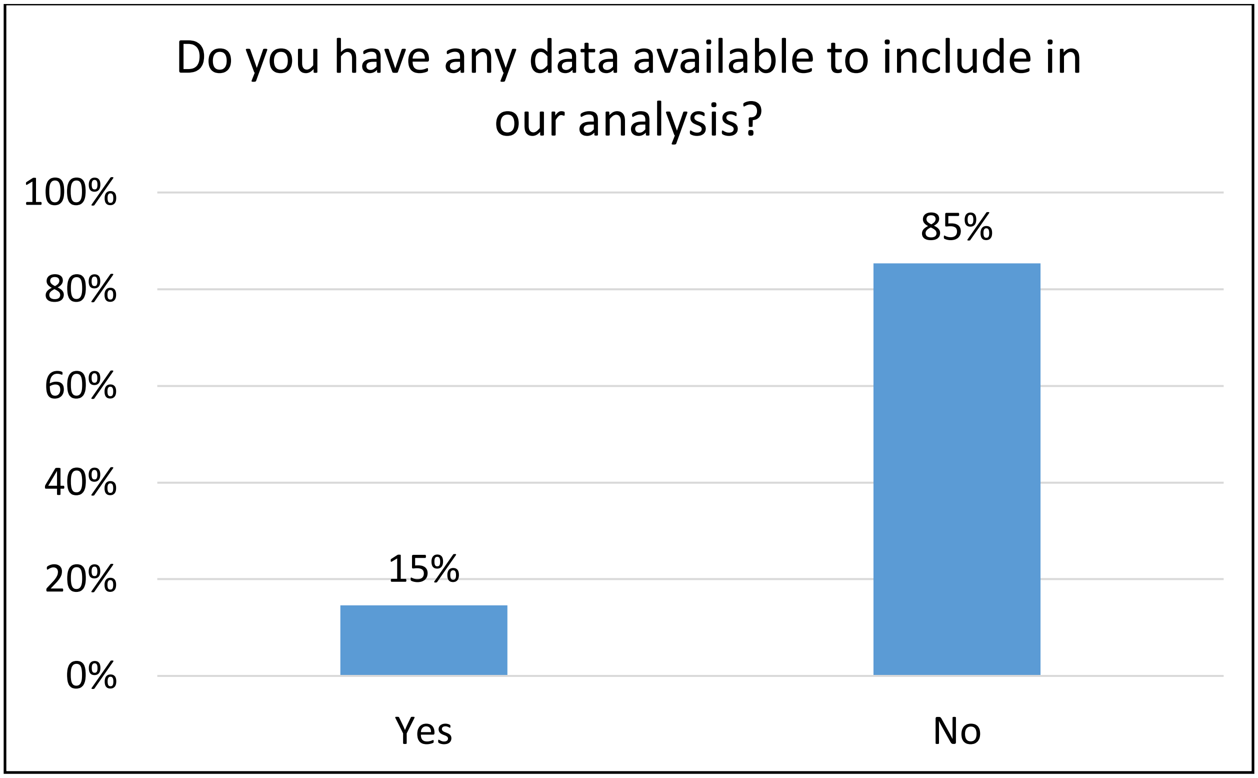

Figure 17. Graph. Agency data availability.

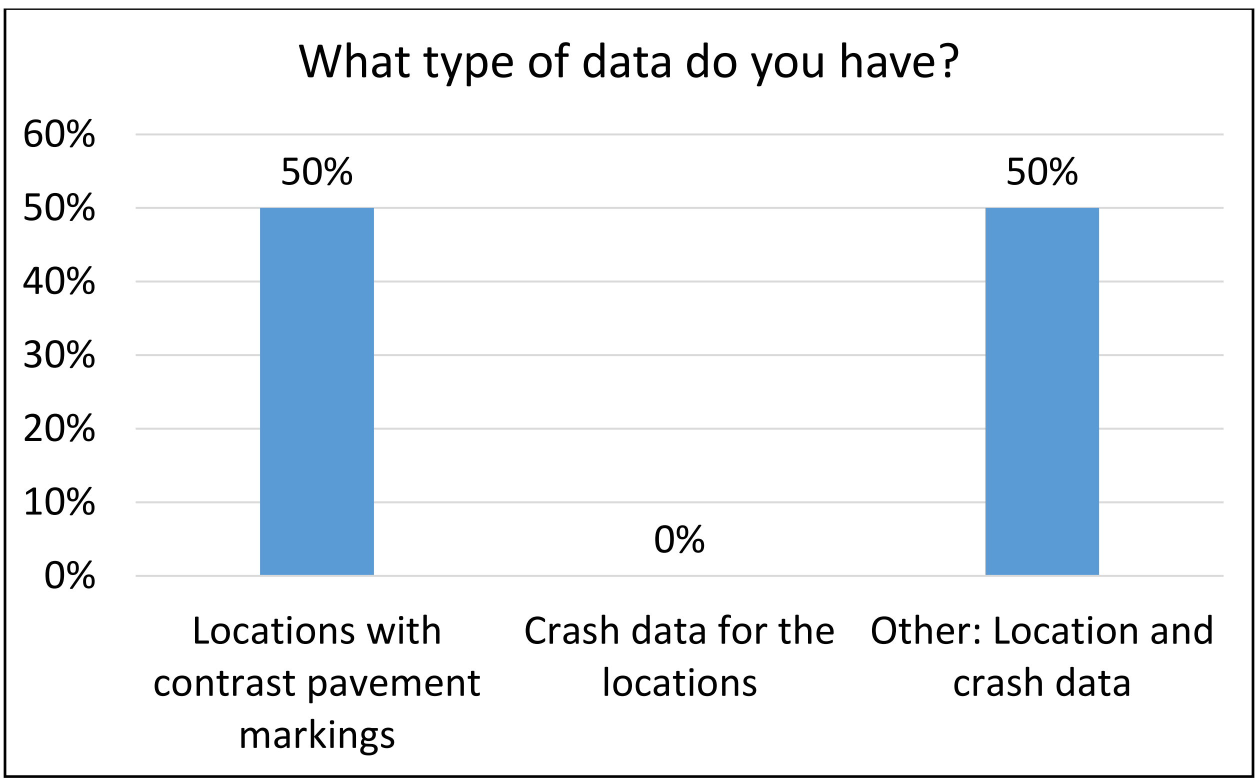

Figure 18. Graph. Data and location availability.

CHAPTER 4: STUDY LOCATIONS AND DATA COLLECTION

Data were obtained from multiple DOTs for this research, which were identified through the national survey. Primary focus was given to data obtained from IDOT, with additional sites being used to increase the sample size of the analysis. Five other agencies—California, Texas, Iowa, Virginia, and Pennsylvania—provided additional locations and crash data to increase the sample size and to improve the validity of the results. Based on the available data, installation dates, and crash-reporting methods, a database was developed. This chapter offers a description and examples of the study sites and the data that were obtained during the data collection procedure. Figure 19 shows the contributing states where data were collected for the expanded analysis.

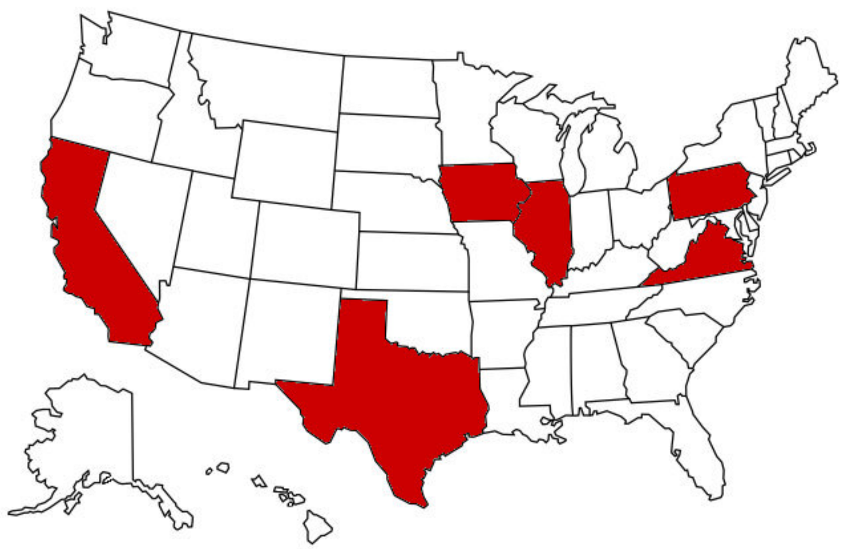

Figure 19. Map of states used in the analysis.

DATA PREPARATION

All crash databases used in this project were sorted prior to analysis. Only departure crashes were retained, consisting primarily of sideswipes, run-off road, and overturn crash types. Each crash was reviewed to ensure the cause was likely departure, with underlying factors such as extreme weather, including snow and ice, removed. Due to contrast pavement markings being relatively new in many states, including Illinois, data were limited to as little as one year at some locations. Other agencies were able to provide two to three years of before and after data, improving the data set.

Data obtained from IDOT were acquired in an Excel format. The data were plotted with mapping software for analysis to ensure crashes fell within the scope of the project sites. Similar procedures were followed for data from other agencies when available in the Excel format. Crash data for other jurisdictions were available via websites that included pre-mapping of the crashes with attribute data. Each crash in the web-based data sets were also carefully reviewed, with only departure-type crashes retained for use in the analysis. It was determined that some agencies use slightly different labeling for departure-type crashes. Figures 20 and 21 show an example location in Illinois with the complementary crash data used in the analysis plotted in mapping software. The segment shown was broken into shorter sections for analysis of approximately one mile in length dependent on easy-to-identify cross streets. Appendix C presents additional example segments from each state used in the analysis. Appendix D presents crash data examples, including segment lengths, AADT, lane configuration, and crash by severity.

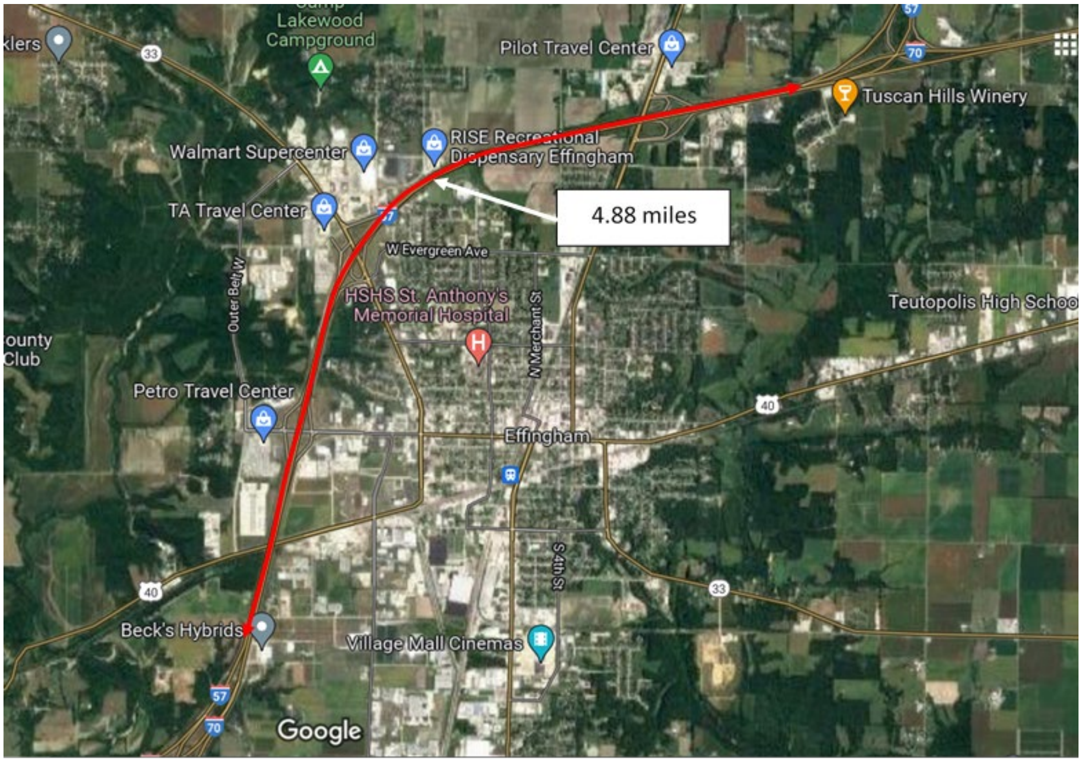

Figure 20. Example location in Effingham, Illinois.

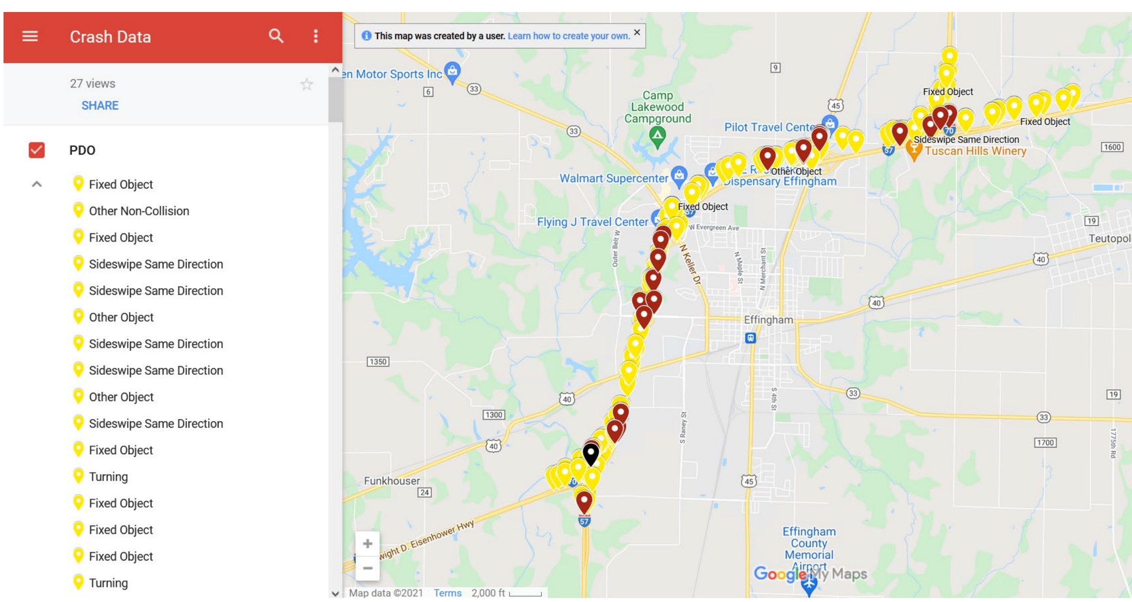

Figure 21. Mapped crashes at segments 5 to 8 in Effingham, Illinois.

A database including segment length, AADT before/after, lane configuration, and crashes by severity were compiled for each site to complete the analysis. Before and after data were used for the analysis at all locations, except for Virginia due to a new roadway being designed with contrast markings. Comparison sites were used for the Virginia locations. Crash severities were separated for analysis to develop CMFs for each crash severity level. During data collection, it was discovered that the data set available from California only reported fatal and injury crashes; however, other agencies provided enough property-damage-only (PDO) crashes to complete the analysis. Table 1 provides example data and site-specific details for Illinois locations; Appendix E presents examples of raw crash data from other states.

Table 1. Site Data for Illinois Bordered Contrast-Striping Locations

Segment	Period	Segment Length (mi)	AADT	Number of Lanes	Fatal	Injury	PDO	Total
1	Before	1.11	129709	6	0	2	22	24
1	After	1.11	133600	6	0	1	16	17
2	Before	1.02	119709	6	0	4	19	23
2	After	1.02	123300	6	0	0	12	12
3	Before	1.14	130000	8	0	1	21	22
3	After	1.14	133900	8	0	1	7	8
4	Before	0.75	44854	6	0	1	9	10
4	After	0.75	46200	6	0	0	18	18
5	Before	1.18	42524	6	0	1	5	6
5	After	1.18	43800	6	0	0	7	7
6	Before	1.03	38058	6	0	0	5	5
6	After	1.03	39200	6	0	1	4	5
7	Before	1.32	37864	6	0	0	3	3
7	After	1.32	39000	6	0	0	2	2
8	Before	1.35	40485	6	0	0	1	1
8	After	1.35	41700	6	0	0	4	4
9	Before	1.20	22330	4	0	0	3	3
9	After	1.20	23000	4	0	0	5	5
10	Before	1.00	18544	4	0	0	4	4
10	After	1.00	19100	4	0	0	2	2
11	Before	1.30	19515	4	0	0	6	6
11	After	1.30	20100	4	0	0	4	4
12	Before	1.18	23010	4	0	0	2	2
12	After	1.18	23700	4	0	0	4	4
13	Before	0.07	54563	6	0	0	2	2
13	After	0.07	56200	6	0	0	2	2
14	Before	0.11	58641	6	0	1	1	2
14	After	0.11	60400	6	0	0	0	0

SUMMARY

Data were collected from six states: Illinois, Virginia, Iowa, Texas, California, and Pennsylvania. Target crashes included roadway departure at all severity levels on high-speed roadways in urban and suburban areas. Data were collected on 70 miles of roadway that included nearly 2,800 total crashes.

CHAPTER 5: CRASH MODIFICATION FACTOR DEVELOPMENT

Development of CMFs relies heavily on available data. Typically, three years of data before and after installation are recommended to have acceptable results. The before–after approach using the EB method was used to quantify the effects on contrast pavement markings for this study. The analysis followed procedures outlined in the *Highway Safety Improvement Program* (*HSIP*) manual (Herbel et al., 2010) and the *Highway Safety Manual* (*HSM*) (AASHTO, 2010). This method was chosen for its ability to control regression to the mean bias and provide reliable results when ample data are available. With the before–after method, the only change at a site should be the change being evaluated to reduce errors. Study sites were carefully selected to only include locations where the only change was the installation of contrast pavement markings and no other design factors were altered. Even with the site controlled to just striping changes, other factors can still influence crash rates. A driving factor in crash rates and crash prediction models that must be accounted for was AADT. AADT historically changes with many locations reporting an increase in traffic typically 3% per year. AADT can greatly increase crash predictions when modeling or negate the effect of some treatment if not taken into consideration.

METHODOLOGY

The facility types where data were available for the analysis proved to be urban/suburban interstates, freeways, and tollways, as defined in the *HSM*. Calibrated safety performance functions (SPFs) developed for use in the *HSM* were used in the analysis (AASHTO, 2010). The overall goal of the analysis was to develop CMFs for RwD crashes on urban/suburban high-speed roadways (interstates, freeways, and tollways) that can be used in the design process in conjunction with the *HSM* to design safer roadways and reduce the number of fatal and severe injury crashes caused by RwDs. The equations presented below were used to quantify the safety benefit of contrast pavement markings. A previous study (IDOT, 2018) had calibrated the SPFs to Illinois roadways, which improved the results of the analysis by limiting error.

$$SPFs = \mu_i = (SL)_i \times e^a \times (AADT)^b$$

Figure 22. Equation. Safety performance function.

Where, *SPF* is safety performance function, μ_i is the expected number of crashes for given segment *i*, SL_i is the segment length in miles of segment *i*, $AADT_i$ is the average annual daily traffic of segment *i*, and *a* and *b* are the regression coefficients (unique to roadway type).

$$W = \frac{1}{1 + \frac{\mu_b * Y}{d}}$$

Figure 23. Equation. Weighting factor for prediction models.

Where, *W* is weight, μ_b is predicted number of crashes using the SPF, *d* is overdispersion perimeter unique to each set of regression coefficients, and *Y* is number of years in the before periods.

$$E_b = P * W * A * (1-W)$$

Figure 24. Equation. Crash estimation for before treatment.

Where, *Eb* is estimated number of crashes in the before period, and *A* is observed number of crashes in the before period.

$$N_{expTB} = W * (N_{preTB}) + (1 - W) * N_{obsTB}$$

Figure 25. Equation. Estimate for expected crashes in the before treatment.

Where, *NexpTB* is expected number of crashes before treatment, *NpreTB* is predicted number of crashes before treatment, and *NobsTB* is observed number of crashes before treatment.

$$\sigma = \sqrt{((1 - W))} * E_b$$

Figure 26. Equation. Standard deviation of crash estimate.

Where, *σ* is standard deviation.

$$S = \frac{1}{\sigma^2}$$

Figure 27. Equation. Standard error of crash estimate.

Where, *S* is standard error.

$$E_a = E_b * \frac{\mu_a}{\mu_b}$$

Figure 28. Equation. Expected crash frequency estimate.

Where, E_a is expected crash frequency in the after period if no treatment is used, E_b is expected crash frequency before treatment, μ_a is predicted crash frequency in the after period (without treatment), and μ_b is predicted crash frequency in the before period.

$$CMF = \frac{N_{obsAT}}{E_a}$$

Figure 29. Equation. Crash modification factor calculation.

Where, *CMF* is crash modification factor, and *NobsAT* is number of observed crashes after treatment.

The results of all study sites were combined using the meta-analysis method, where weighting was used to give sites with less standard error more weight in the final CMF values.

$$CMF = \frac{\Sigma W_i CMF_i}{CMF_i}$$

Figure 30. Equation. Crash modification factor equation for meta-analysis method.

Where, *CMF* is crash modification factor for each site, and *W* is weighting factor for each unique CMF.

$$W = \frac{1}{SE^2}$$

Figure 31. Equation. Weighting formula for meta-analysis method.

Where, *SE* is standard error of each predicted SPF.

Table 2 shows the unique coefficients for each SPF, including overdispersion parameters used in the weighting calculation. These coefficients and overdispersion parameters were calibrated for each Illinois roadway in a previous study. They were also used for the study sites in other states to remain consistent with the prediction model effects.

Table 2. Estimated Coefficients of SPF

Urban Freeway	Intercept (a)	AADT Log (b)	Overdispersion (*d*)
Four Lane	−5.2895	0.4632	0.226
Six Lane	−13.9685	1.3672	0.5715
Eight Lane	−9.093	0.9747	0.5981

Following the aforementioned methodology and calculation procedures, CMFs were developed for three roadway types—four, six, and eight lanes—at three crash severity levels—total, fatal/injury, and PDO. Table 3 lists the number of lane miles and crash totals in each severity used in the development of each CMF. Data for the four-lane sections were limited, resulting in the development of only total and PDO crashes for that lane configuration. Overall, the results indicate a positive effect with the use of contrast pavement markings, with all roadway types and crash severity levels showing a decrease in crashes. The results show a reduction between 12% and 29% for total crashes, 7% to 19% for fatal/injury crashes, and 5% to 16% for PDO crashes.

Table 3. Crash Modification Factors

Miles	# of Lanes	CMF Total	# of Crashes	CMF F/I	# of Crashes	CMF PDO	# of Crashes
4.68	4	0.84	30	–	0	0.84	30
17.89	6	0.88	545	0.93	158	0.87	387
46.52	8	0.71	426	0.81	829	0.95	343

TESTING FOR LEAD/LAG VS. BORDERED DIFFERENCES

Two types of contrast pavement marking designs were tested in the study. Bordered designs were found to be the predominate design in the data set, with limited sections of lead/lag designs in Pennsylvania, consisting of just over five miles on six-lane roadways. Each roadway was broken into shorter sections with one-mile segments being the targeted length; some sections were shorter due to contrast pavement markings being installed only on bridge decks. Comparable sections of the bordered design from two states, Illinois and Iowa, were used to test for differences between the two contrast marking designs. Standard statistical testing with software were conducted with a focus on testing for differences in groups where the before versus after crash reductions of each segment were analyzed. No differences in performance were detected between the tested groups.

Tukey post-hoc testing was used to test for differences between the groups. The hypothesis was that there are no differences between the mean of the groups. An alpha level was set at 0.05; Tukey testing found no differences between the three tested groups, with a p-value of 0.229 reported.

SUMMARY

The development of the CMFs followed the recommended procedures in the *HSIP* and *HSM* (Herbel et al., 2010; AASHTO, 2010). Each segment was analyzed with a unique CMF, and the weight was calculated. The results of each site were combined into a single CMF for each severity level and roadway type utilizing the meta-analysis approach where CMFs with smaller error have more weight, a method used to control bias.

To improve the results, calibrated SPFs were used that are unique to the Illinois roadways used in the analysis. To increase the sample size, data were obtained from other states. The calculated CMFs show a decrease in RwD crashes for all severities on all roadway types analyzed. Due to the limited data on four-lane roadways, a CMF was only developed for total and PDO crashes, as there were no or limited fatal or injury crashes on the evaluated roadway sections.

CHAPTER 6: BENEFIT-COST TOOL

A benefit-cost analysis can be a useful tool to justify project selection or to determine the validity of a single option. The researchers developed a user-friendly benefit-cost analysis tool in a basic worksheet format to allow easy use for project selection. The following sections and figures show the separate sections of the benefit-cost analysis tool and explain in detail the user input and calculated results. Appendix F presents an example calculation using the benefit-cost analysis sheet.

WORKSHEET OVERVIEW

The worksheet requires users to enter analysis site details that are used both to keep track of the analysis site and for calculations that estimate the benefit-cost ratio of contrast pavement markings. A color scheme was adopted to simplify user interaction. Yellow is used for all required user inputs, blue is used for suggested values that may change as cost increases, and green shows calculated values. Green cells are locked to protect the formulas and can be adjusted with a password.

USER INPUTS

User inputs are necessary for the worksheet to complete the benefit-cost analysis that are site specific, including segment length, AADT, and crash history. The following section provides details on the inputs including suggested values, when available. The first sections of the user input worksheet are shown in Figure 32.

IDOT Benefit-Cost Analysis Tool for Contrast Pavement Markings
Input Sheet

Agency: Illinois Department of Transportation
Project Name: R27-223: CMFs for Contrast Pavement Markings

User Input Value	(yellow)
Suggested Value	(blue)
Calculated Value	(green)

Road Segment Characteristics	***User Input Value***	***Suggested Value***	***Unit***
Road ID	I-57/70		
County	Williamson County		
Average Speed Limit	65	65	mi/hr
Number of Lanes	8	4, 6 or 8 lanes	Lanes both directions
Mile Maker (MM) Start	10		
Mile Maker (MM) End	100		
Segment Length	90		Miles
Annual Average Daily Traffic (AADT)	60000		Veh/Day
Roadway Crash History	***User Input Value***	***Suggested Value***	***Unit***
Fatal (K)	2	3 to 5 year average	Crashes per year
Disabling Injury (A)	5	3 to 5 year average	Crashes per year
Evident Injury (B)	8	3 to 5 year average	Crashes per year
Possible Injury (C)	7	3 to 5 year average	Crashes per year
PDO (O)	22	3 to 5 year average	Crashes per year
Total Crashes	44	3 to 5 year average	Crashes per year

Figure 32. Image. Input sheet for the contrast pavement marking tool.

ROAD SEGMENT CHARACTERISTICS

The road segment characteristics include information used for documentation purposes and inputs used in the calculation procedures. Some values have a suggested range based on the development of the CMFs.

Road ID

Users can input the road ID for the purpose of documentation. This input is not used in any calculations.

County

Users select the county input from the drop-down list of all 102 counties in Illinois. This input provides users with additional documentation regarding the location used in the analysis.

Average Speed Limit

The average speed limit can be input for documentation purposes. The speed limit of roadways used in the development of the CMFs is listed as a suggested value of 65 miles per hour (mph).

Number of Lanes

The number of lanes in both directions must be input by users. The tool was developed for four-, six-, and eight-lane urban/suburban interstate, freeway, and tollway segments. This user-selected value will be used in the calculations for the benefit-cost analysis.

Segment Length and Mile Markers

Segment length is calculated in miles based on the user input of starting and ending mile markers. A positive value is returned regardless of the order mile markers are input.

Annual Average Daily Traffic

The annual average daily traffic (AADT) value is the total number of vehicles in both directions of travel along the segment of interest. This user input value is used for documentation purposes.

Crash Data

Crash data from the segment of interest are a required input. Users should identify the average annual crashes experienced on the segment over a three- to five-year period. Inputs are required for fatal, injury, and PDO crashes separately. The three- to five-year average of each crash severity will give a better representation of the potential benefits in terms of crash reductions that can be expected over time at a treatment site. The crash data inputs are used to calculate the benefit-cost analysis and crash reduction.

BENEFIT-COST ANALYSIS INPUTS

The inputs in this section are used to quantify the present value cost of the project. The inputs are used with standard economic analysis formulas. Figure 33 displays the inputs and calculated values for the benefit cost and project cost.

Benefit-Cost Analysis Inputs	*User Input Value*	*Suggested Value*	*Unit*
Analysis Period	8	5 to 8 years	Years
Discount Rate	3%	3%	%
Inflation Rate	3%	Yearly increase from base year (2022)	%
Year of Study	2023		
Project Costs	*User Input Value*	*Suggested Value*	*Unit*
Contrast Pavement Markings	$ 3.50	$ 3.50	Cost per 40 feet of lane line
Contrast Pavement Markings (cost per lane line)	$ 41,580.00		Cost per lane line
Standard Tape Markings	$ 1.75	$ 1.75	Cost per 40 feet of lane line
Standard Tape Markings (cost per lane line)	$ 20,790.00		Cost per lane line
Itemized Costs (Contrast Markings)			
Installation Cost	$ 249,480.00		
Annual Maintenance Cost	$ 8,000.00		
Itemized Costs (Standard Tapes)			
Installation Cost	$ 124,740.00		
Annual Maintenance Cost	$ 3,000.00		

Figure 33. Image. Benefit-cost analysis inputs.

Analysis Period

The analysis period value will be used to calculate the present value of the project. Users should input the number of years they expect the striping to last before replacement is required. Suggested values of five to eight years are suggested based on the current projected life of contrast pavement markings in Illinois.

Discount Rate

A pre-set standard discount rate of 3% is recommended for calculations. Users have the option of updating the discount rate as necessary. The discount rate is used to calculate the present value of the cost and benefit equations.

Inflation Rate

The inflation rate should be input by users based on the average increase per year from the base year of 2022. The value will be used to adjust the cost of crashes into today's dollars. A recommended inflation rate is set at 3%.

Year of Study

The year of study represents the year the analysis is being conducted. The value will be used to adjust the cost of crashes, taking into consideration the user input inflation rate.

Project Costs

The project costs must be input by users as a cost per foot, assuming 10-foot striping with 30-foot gaps. The inputs of cost per foot, segment length, and number of lanes are used to quantify the cost per mile.

Itemized Costs (Contrast Markings and Standard Tapes)

The total cost of installation and any annual maintenance cost are input in the itemized cost section. Installation cost is a calculated value based on user inputs from the project cost section. Maintenance cost is currently believed to be zero for contrast striping but may increase in the future as retroreflective testing requirements are enacted. Users can directly input the projected annual maintenance cost over the life of the contrast pavement markings.

Inputs for the standard tape option is also available. This input can be used to compare alternatives with results showing the increased benefit of contrast striping.

CALCULATED VALUES

Figure 34 shows the calculated values section of the worksheet. Estimated benefits associated with contrast pavement markings in terms of dollars and crash reductions are presented in this section.

Itemized Annual Benefits			
Fatal (K)	$ 2,918,957.64		
Disabling Injury (A)	$ 393,184.46		
Evident Injury (B)	$ 230,084.90		
Possible Injury (C)	$ 114,424.38		
PDO (O)	$ 15,597.14		
Total	$ 3,672,248.52		
Estimated Number of Crash Reductions per Year			
Fatal (K)	0.38		
Disabling Injury (A)	0.95		
Evident Injury (B)	1.52		
Possible Injury (C)	1.33		
PDO (O)	6.38		
Total	12.76		
Benefit-Cost Analysis Results			
Present Value Cost ($) Contrast Markings	$ 305,637.54		Installation and annual costs
Present Value Benefits ($) Contrast Markings	$ 25,778,054.26		Annual benefits over life (n)
Benefit-Cost Ratio (Contrast Markings)	84.3		
Present Value Cost ($) Standard Tapes	145799.1		
Benefit-Cost Ratio Between Contrast and Standard	161.28		
Project Feasibility	Feasible		

Note: For 4 Lane sections only PDO data is available due to limited locations and few fatal/injury crashes.
Note: The calculations show the benefits and reductions in roadway departure crashes.

Figure 34. Image. Calculated benefits and benefit-cost ratio.

Itemized Benefits

The itemized benefits section provides users with the estimated quantitative benefit in terms of crash reductions. Benefits for each crash severity level are calculated using the crash history of the segment of interest. CMFs are used to estimate crash reduction percentages and cost savings due to crashes in today's dollars (analysis year).

Crash Reductions

The number of crash reductions that can be expected by contrast striping installation will be reported in this section. The calculation is based on the developed CMFs and crash history of the segment of interest.

Benefit-Cost Analysis Results

The results of the benefit-cost analysis are reported in this section. Present value cost and present value benefits are calculated using user inputs from previous sections and used to calculate the benefit-cost ratio. The projected benefit-cost between contrast and standard striping is also calculated. Project feasibility is calculated and reported, where a benefit-cost ratio greater than one would be considered feasible.

CHAPTER 7: CONCLUSIONS AND OBSERVATIONS

Roadway departure crashes account for a disproportional amount of fatal and severe injury crashes on high-speed roadways in the United States. Several countermeasures exist to address RwD crashes, but no past studies have evaluated contrast pavement markings' ability to reduce RwDs. Furthermore, the use of contrast pavement markings is becoming a national trend, with most states expanding or adopting their use. At the time of this research no agency had quantified the safety benefit of contrast pavement markings in regards to crash reductions. To justify the use and extra expense of contrast markings, IDOT initiated this research to quantify the safety benefit of contrast pavement markings and to develop a benefit-cost analysis tool that can be used to calculate crash reductions, cost savings in terms of crashes, and a benefit-cost ratio.

The extensive literature review found that past studies had focused on lane line visibility in various conditions, including the effects of retroreflectivity. No past studies were identified that had studied contrast pavement markings or their safety benefits. The literature review did identify two common designs—bordered and lead/lag—with both being commonly used by DOTs. Past survey methods were also reviewed to improve the response rate and identify optimal question structure. Based on those findings, an 88% completion rate was obtained by this project's survey. A review of CMF development methods was also conducted that focused on *Strategic Highway Research Program (SHRP)* and *HSM* methods to increase the validity of the results, selecting the best approach for the available data set.

A national-level survey was disseminated to key personal at DOTs and highway agencies. The results indicated an increased use in contrast striping at the national level, with 75% of states reporting its use. The survey further identified that no responding agencies have conducted a quantitative safety benefit analysis related to contrast striping. Other key findings were that most agencies are using contrast striping on Portland cement concrete sections of high-speed roadways, with nearly equal use between the designs of bordered and lead/lag. Years of use ranged between less than 1 and 15 years, with cost of installation ranging between less than $2 and more than $10 per lane foot.

The crash data analysis consisted of a before–after EB approach. To increase the sample size, data from other states were solicited though the national survey. Data from five additional states were found to be suitable for use in the analysis. Crash data were obtained for three roadway types with contrast pavement markings: four lane (4.68 miles), six lane (17.89 miles), and eight lane (46.52 miles). A sufficient number of crashes were found on the six- and eight-lane sections; however, limited crashes were available on the four-lane sections, limiting the analysis to total or PDO crashes. Crash data were sorted by severity and with only RwD crash types retained for use in the analysis. Findings suggest a safety benefit related to contrast pavement markings occurs on all roadway types and all crash severity levels analyzed in the study.

A benefit-cost analysis tool was developed to assist planning and design engineers with decision making related to the additional expense of contrast pavement markings when compared to standard tapes. The benefit-cost analysis tool includes user inputs that are necessary to calculate the present value cost related to contrast striping installation. Maintenance versus present value benefits are then calculated from the reduction of crashes using the CMFs developed with this project and the current cost of crashes adjusted for analysis year input by the user. With reductions in crashes ranging from 12% to 29% for total, 7% to 19% for fatal/injury, and 5% to 16% for PDO, the benefit-cost ratio was found to be greater than one for all example sections tested during development, indicating a strong overall benefit of using contrast striping.

REFERENCES

AASHTO. (2010). *Highway Safety Manual.* American Association of State Highway and Transportation Officials.

Abbas, A. R. (2011). *Nighttime Visibility of 3M AWP and 3M 380WR ES Durable Tape under Dry, Wet, and Rainy Conditions.* Ohio Department of Transportation.

Ceifetz, A., Yassin, J., Andridge, P., Kwigizile, V., Oh, J.-S., & Burdick, B. (2017). *Evaluating Road Delineation Practices in Michigan.* Michigan Department of Transportation.

Dougald, L. E. (2010). *Best Practices in Traffic Operations and Safety: Phase II: Zig-zag Pavement Markings.* Virginia Department of Transportation.

Federal Highway Administration. (2019, September 10). *Crash Modification Factor Clearinghouse*. Retrieved September 19, 2019, from http://www.cmfclearinghouse.org/results.cfm

Furnas, B., Giancola, A. R., Kalchbrenner, J., McKee, D., Moon, N., & Ranck, F. (2008). *Low Cost Local Road Safety Solutions.* American Traffic Safety Services Association.

Gates, T. J., & Hawkins, H. (2002). *The Use of Wider Longitudinal Pavement Markings.* Texas Transportation Institute, The Texas A&M University System.

Gross, F., Persaud, B., & Lyon, C. (2010). *A Guide to Developing Quality Crash Modification Factors.* Federal Highway Administration.

Herbel, S., Laing, L., & McGovern, C. (2010). *Highway Safety Improvement Program (HSIP) Manual.* Federal Highway Administration.

Lawrence, M., Hachey, A., Bahar, G., & Gross, F. (2018). *Highway Safety Benefit-Cost Analysis Guide.* Federal Highway Administration Office of Safety.

McGee, Sr., Hugh W. (2018). *Practices for Preventing Roadway Departures.* National Cooperative Highway Research Program.

Migletz, J., Fish, J. K., & Graham, J. L. (1994). *Roadway Delineation Practices Handbook.* Office of Safety and Office of Technology Applications, Federal Highway Administration.

Neemann, M. (2013). *New Painted Contrast Markings Increase Visibility, Save Money.* Roadrunner.

Omranian, S., Sharif, H., Dessouky, S., & Weissmann, J. (2018). *Exploring rainfall impacts on the crash risk on Texas roadways: A crash-based matched-pairs analysis approach.* Accident Analysis and Prevention.

Pike, A. M., & Carlson, P. J. (2018). *Evaluation of the Effects of Pavement Marking Width on Detectability by Machine Vision: 4-inch vs. 6-inch Markings.* American Traffic Safety Services Association.

Pike, A., & Barrette, T. (2020). *Pavement Markings—Wet Retroreflectivity Standards.* Local Road Research Board and Minnesota Department of Transportation.

Traffic & Transit. (n.d.). *Wet Retroreflective Pavement Markings can help Prevent Crashes*. Retrieved September 22, 2020, from https://www.traffictransit.com/wet-retroreflective-pavement-markings-can-help-prevent-crashes

TxDOT. (2004). *Pavement Marking Handbook.* Texas Department of Transportation: Traffic Operations Division.

Varghese, C., & Shankar, U. (2007). *Passenger Vehicle Occupant Fatalities by Day and Night—A Contrast.* US DOT National Highway Traffic Safety Administration.

APPENDIX A: SURVEY QUESTIONNAIRE

This appendix displays the survey questions presented to agencies.

Default Question Block

Q1. Please complete all questions in the survey. Some questions will allow for more than one answer.
This survey will take approximately 10 minutes to complete.

Q2. Is your agency using contrast pavement markings?

Yes
No

Q3. What configuration of contrast pavement markings are being used by your agency?

Border
Border with lead/lag
Lead/lag

Q4. Are you considering the use of contrast pavement markings

Yes
No

Q5. What decisions are being used to adopt contrast pavement markings?

Safety benefit
Driver comfort

Other: please explain

Q6. What type of pavement is your agency using contrast pavement markings?

Portland Cement Concrete (PCC)

Hot Mix Asphalt (HMA)

Both PCC and HMA

Q7. What roadway types is your agency using contrast pavement markings?

Freeway/Interstates

Highways

Local roads

Other: Please explain

Q8. How did your agency make the decision to implement contrast pavement markings?

Crash reductions

Traffic flow improvements

Other

Q9. How many years has your agency been using contrast pavement markings? (Please insert number of years)

Q10. What benefits have been realized from the use of contrast pavement markings?

Crash reductions

Driver comfort

Other: Please explain

Q11. Has your agency quantified the results related to crash reductions?

Yes

No

Q12. Can you share the results of your quantitative analysis related to crash reductions?

Yes

No

Q13. Do you feel that contrast pavement markings are cost effective?

Yes

No

Q14. What is the cost per lane foot of installing contrast pavement markings using grooving on your roadways?

Q15.

Do you have any data available to include in our analysis?

Yes

No

Q16. What type of data do you have?

Locations with contrast pavement markings

Crash data for the locations

Other: Please explain

Q18. Please provide contact information of persons with location information. Email and/or phone number.

Powered by Qualtrics

APPENDIX B: RAW SURVEY RESPONSES

This appendix provides unsummarized responses from participating agencies to the open-ended or other survey questions.

Table 4. Open-ended responses to the following question: What roadway types is your agency using contrast pavement markings?

Other: Please explain - Text
We apply contrast on any new construction project when new PCC pavement is constructed to provide contrast with the new / bright surface. We only have two of our 7 districts who are equipped to maintain these markings, St. Louis and our Springfield districts, who refresh the contrast every other year
any PCC road
Urban crosswalks and some interstate lane lines.
contrast markings are used for all lane lines on state maintained roads
Tollway
Contrast markings are mostly limited to freeways and expressways - on PCC roads and longer bridge decks. In rare cases VDOT may have some contrast markings on non-limited-access roads, however VDOT has very few PCC roads off the freeway/interstate system.
under question 6- we have used on Polymer OL as well. The use has been limited, but I have seen the PCP ones last a very long time.

Table 5. Open-ended responses to the following question: How did your agency make the decision to implement contrast pavement markings?

Other - Text
We began implementing contrast during our smoother roads initiative. As part of that program we diamond ground existing concrete pavements to reprofile them to a smoother condition and that refreshed surface created the lack of contrast with our lane lines. At the same time we were installing wet reflective tape for lane lines on all pavement types. The contrast tape was our first introduction into contrast markings around 2005-2006 time frame. We continued the contrast on new concrete even when we transitioned back to a waterborne marking
CAV detection
ADOT use it on light colored pavement to provide for better contrast
concrete glare
Looks better.
MUTCD
Automated Car Industry
The contract markings are being used in an experimental aspect in a long term work zone on an interstate.
Wanted improved visibility of markings on certain concrete pavements and high traffic routes
visibility
complaints about seeing markings
Visibility in Certain Daylight Conditions
sun glare
visibility
Visibility
They were implemented to help improve the visibility of our striping, specifically the white striping on concrete.
Connected/autonomous vehicles, safety
Increase visibility especially on new "white" concrete pavement.
Drivers clearly prefer contrast markings on light-colored surfaces, however to our knowledge no one has ever quantified reduction in crash risk from such markings.
Improve marking visibility.
improve driver visibility for white skip lines on concrete roadways
To address concerns about not being able to see the white markings in certain conditions
Consideration of machine vision on newer vehicles
Improved pavement marking visibility
trials, contrast on PCCP with PCP, use is limited
Wanted more visible markings on high traffic concrete pavements
Lane visibility
Decision made from State Headquarters
Studies on autonomous vehicles
Driver's comfort, Connected vehicles
Visibility on light colored pavements
Automation in vehicles and for safety

Table 6. Open-ended responses to the following question: What benefits have been realized from the use of contrast pavement markings?

Other: Please explain - Text
We have no documentation on crash reductions, it was adopted primarily to improve the visibility of lane line on bright concrete surfaces where the lane lines were not clearly visible without the contrast marking
Increased visibility and hoping long term data reflects crash reduction
After counter measures yet to be determined for crash reduction
Appearance.
Automated Car Industry
The work zone application is still being evaluated.
visibility
visibility
Better visibility
The striping is more visible which could lead to crash reductions but we do not have any data on hand currently to confirm.
unknown at this point.
unknown; we don't use them enough to be able to collect meaningful data
In the last 2-3 years, there has been significant discussion about such markings benefiting vehicles relying on machine vision.
Unknown
We haven't studied the before and after crashes so this is unknown. Driver comfort is a benefit.
Lack of comments from the public that they can't see the markings
unknown
more contrast
Both of the above
Better visibility on PCC
Keeping DOT paint crew off of the interstate

Table 7. Open-ended responses to the following question: What is the cost per lane foot of installing contrast pavement markings using grooving on your roadways?

What is the cost per lane foot of installing contrast pavement markings using grooving on your roadways?
We currently are a waterborne state and do not groove in our markings. I believe when we were grooving in the contrast tape the grooving was around $0.45 L.F. We are revisiting using grooving to extend the life of our markings, but have not implemented this yet to have any updated figures.
double the cost of conventional
for 4" tape $4.50 / ft
3-6 dollars per l
expensive
It varies as we use it for Thermoplastic, MMA and Warranty Tape. The bid item is per linear feet include Stripe + Contrast
Approx. $5.50 per linear foot for 4" wide white marking
7"- $11/ft , 11"-$14/ft, messages-$44/sf
$7-8 Tape, $3-4 Epoxy
$0.85-$1.35
Unknown
$1.55
$7.00 LF
$4.35 - $5.00/ LF
$8 for 4" with 1.5" border
$0.60/ft
unk. See Dan Waddle, ndot
unknown
Between $4.35 and $5.00 per linear foot. That is based on a 10' skip 7" wide (1.5" black outline - 4" white - 1.5" black outline)
VDOT does not use grooving
$10 per foot, black only
Have not grooved contrast markings yet.
Unknown. There is not a specific pay item to track.
$5 for tape, $3 for epoxy
$1.00 - 1.25 per foot for 6"
8.00
do not have that. under number 13 above, they may be cost effective if a need for contrast exists
$6.33
$0.75-0.90 (We don't groove contrast marking)
Don't know
$2.65
0.62
$.03 per gross foot
$1.10
varies
$8.85 for 4"

Table 8. Open-ended responses to the following question: What type of data do you have?

Other: Please explain - Text
Survey by other DOTs
Bid Documents with unit Cost
VDOT has bid prices for patterned preformed tape with and without black-bordered ("oreo") contrast properties. Also, note that VDOT's Frequently Asked Questions on the Virginia Supplement to the MUTCD document (http://www.virginiadot.org/business/resources/TED/final_MUTCD/Supplement_FAQs.pdf) recommends that the contrast markings should be used for lane lines, but only for concrete roads/bride decks that are 45+ mph and 200 feet or more in length. There is no requirement to use contrast markings for edge lines or centerlines.
Costs

APPENDIX C: EXAMPLE STUDY LOCATIONS

This appendix provides examples of sites used in the analysis. Most sites were broken into shorter sections for analysis.

ILLINOIS

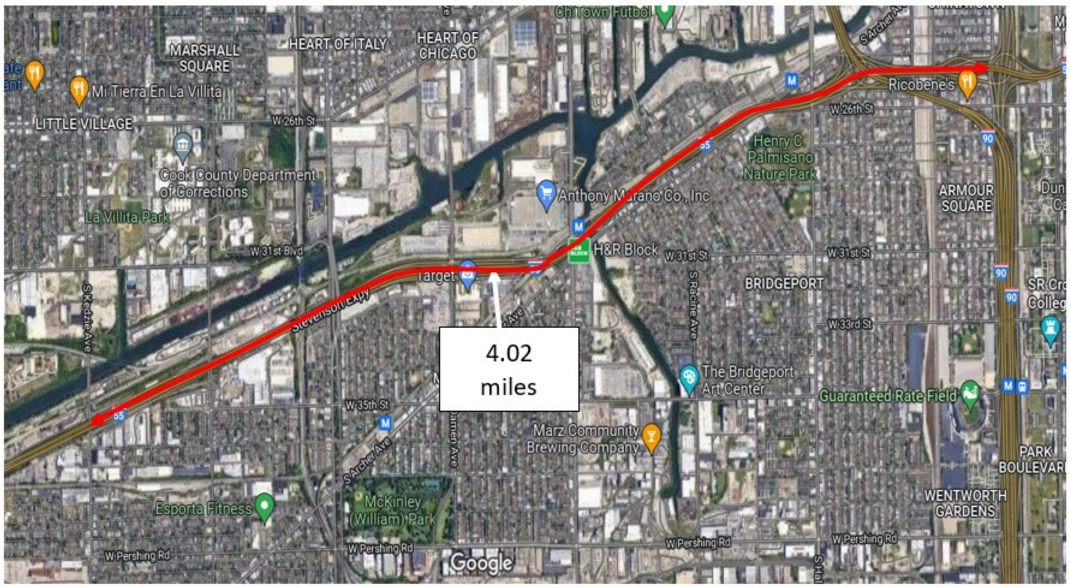

Figure 35. Image. Chicago I-55.

VIRGINIA

Figure 36. Image. Norfolk US 58.

IOWA

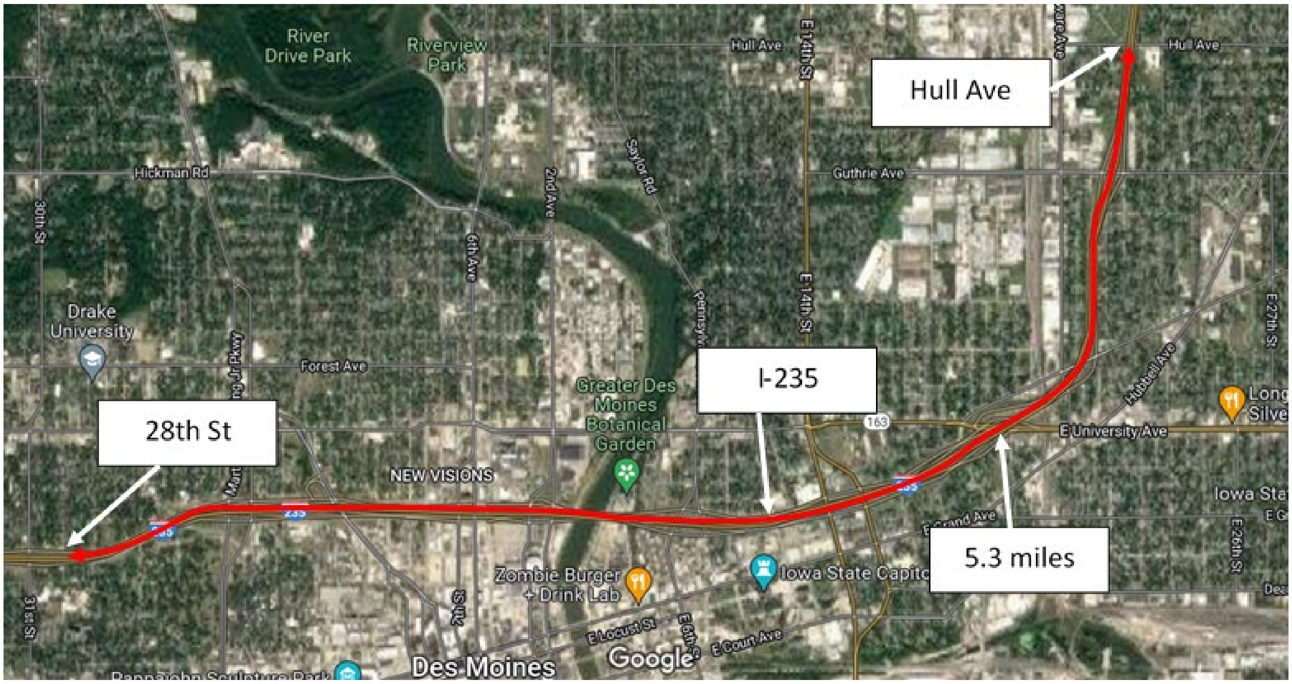

Figure 37. Image. I-235 Des Moines.

TEXAS

Figure 38. Image. President George Bush Turnpike Dallas.

CALIFORNIA

Figure 39. Image. I-5 San Diego.

PENNSYLVANIA

Figure 40**. Image. I-81 Harrisburg.**

APPENDIX D: EXAMPLE SITE DETAILS AND DATA

This appendix provides an example of site details from each state used in the analysis.

Table 9. Example Site Details and Data from Each State Used in the Analysis

State	Segment	Strip Design	Period	Segment Length (mi)	AADT	Number of Lanes	Fatal	Injury	PDO	Total
IL	6	Bordered	Before	1.03	38058	6	0	0	5	5
IL	6	Bordered	After	1.03	39200	6	0	1	4	5
IL	7	Bordered	Before	1.32	37864	6	0	0	3	3
IL	7	Bordered	After	1.32	39000	6	0	0	2	2
VA	2	Bordered	Treatment	0.11	40000	6	0	0	1	1
VA	2	Bordered	Comparison	0.11	40000	6	0	1	0	1
IA	2	Bordered	Before	1.34	113600	6	0	19	35	54
IA	2	Bordered	After	1.34	130500	6	0	6	15	21
IA	3	Bordered	Before	0.61	97300	6	0	7	16	23
IA	3	Bordered	After	0.61	106400	6	0	7	14	21
TX	8	Bordered	Before	0.78	162674	8	0	4	12	16
TX	8	Bordered	After	0.78	156398	8	0	5	7	12
TX	9	Bordered	Before	1.07	162674	8	0	7	16	23
TX	9	Bordered	After	1.07	156398	8	0	5	16	21
CA	6	Bordered	Before	2.27	210000	8	0	44	-	-
CA	6	Bordered	After	2.27	216300	8	2	33	-	-
CA	8	Bordered	Before	2.01	170000	8	2	42	-	-
CA	8	Bordered	After	2.01	175100	8	1	21	-	-
PA	2	Lead/Lag	Before	0.23	66112	6	0	2	0	2
PA	2	Lead/Lag	After	0.23	70760	6	0	0	1	1
PA	5	Lead/Lag	Before	2.11	40823	6	0	15	24	39
PA	5	Lead/Lag	After	2.11	47343	6	0	12	23	35

APPENDIX E: EXAMPLE CRASH DATA

This appendix provides examples of crash data from each state used in the analysis.

ILLINOIS

Table 10. Illinois Crash Data Example

COLL_TYPE	REC_TYPE	LATITUDE	LONGITUDE
FIXED OBJECT	A-INJURY	39.14362877000	-88.54355592000
FIXED OBJECT	PD	39.15735408000	-88.50664947000
FIXED OBJECT	PD	39.15262171000	-88.48659043000
SIDESWIPE SAME DIRECTION	PD	39.14479792000	-88.53449895000
SIDESWIPE SAME DIRECTION	PD	39.14979514000	-88.50284799000
SIDESWIPE SAME DIRECTION	PD	39.14770283000	-88.51627069000
SIDESWIPE SAME DIRECTION	PD	39.14833109000	-88.51232736000
SIDESWIPE SAME DIRECTION	PD	39.11292502000	-88.57080257000
FIXED OBJECT	PD	39.14360394000	-88.54369351000
FIXED OBJECT	PD	39.09503045000	-88.58235637000
FIXED OBJECT	PD	39.15117167000	-88.49578483000
FIXED OBJECT	PD	39.14979432000	-88.50285322000
FIXED OBJECT	PD	39.09645555000	-88.57767656000
SIDESWIPE SAME DIRECTION	PD	39.11878257000	-88.56929096000
FIXED OBJECT	PD	39.10059326000	-88.57474667000
FIXED OBJECT	PD	39.11001926000	-88.57171393000

VIRGINIA

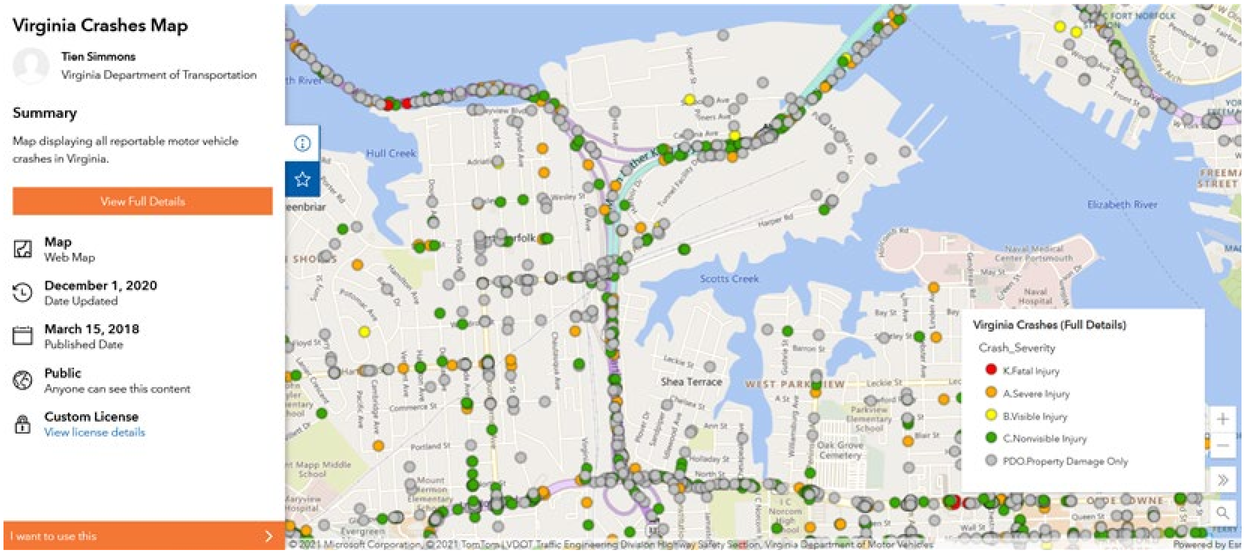

Figure 41. Virginia crash data example.

IOWA

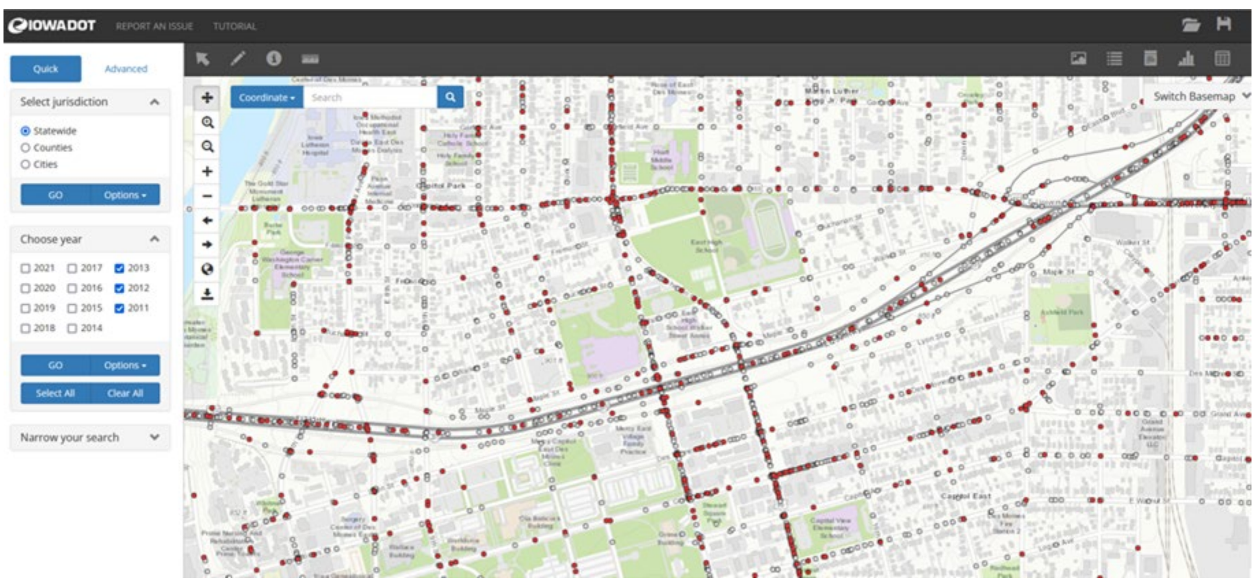

Figure 42. Iowa crash data example.

TEXAS

Table 11. Texas Crash Data Example

COLL_TYPE	REC_TYPE	LATITUDE	LONGITUDE
ANGLE - BOTH GOING STRAIGHT	PDO	33.0840542	-96.82449255
SAME DIRECTION - BOTH GOING STRAIGHT-SIDESWIPE	PDO	33.06652433	-96.82494715
ANGLE - BOTH GOING STRAIGHT	PDO	33.0840542	-96.82449255
SAME DIRECTION - ONE STRAIGHT-ONE LEFT TURN	C-INJURY	33.0778642	-96.82511255
SAME DIRECTION - BOTH GOING STRAIGHT-SIDESWIPE	PDO	33.09013	-96.82297255
ANGLE - BOTH GOING STRAIGHT	PDO	33.0778642	-96.82511255
ANGLE - BOTH GOING STRAIGHT	B-INJURY	33.0778642	-96.82511255
ANGLE - BOTH GOING STRAIGHT	C-INJURY	33.0778642	-96.82511255
SAME DIRECTION - BOTH GOING STRAIGHT-SIDESWIPE	PDO	33.06614523	-96.82463848
ANGLE - ONE STRAIGHT-ONE RIGHT TURN	PDO	33.0778642	-96.82511255
SAME DIRECTION - BOTH LEFT TURN	PDO	33.08701731	-96.82299849
SAME DIRECTION - BOTH GOING STRAIGHT-SIDESWIPE	PDO	33.08270871	-96.82479762
SAME DIRECTION - BOTH GOING STRAIGHT-SIDESWIPE	PDO	33.07059894	-96.82457641
ANGLE - BOTH GOING STRAIGHT	C-INJURY	33.0778642	-96.82511255
SAME DIRECTION - BOTH GOING STRAIGHT-SIDESWIPE	PDO	33.0651304	-96.82481813

CALIFORNIA

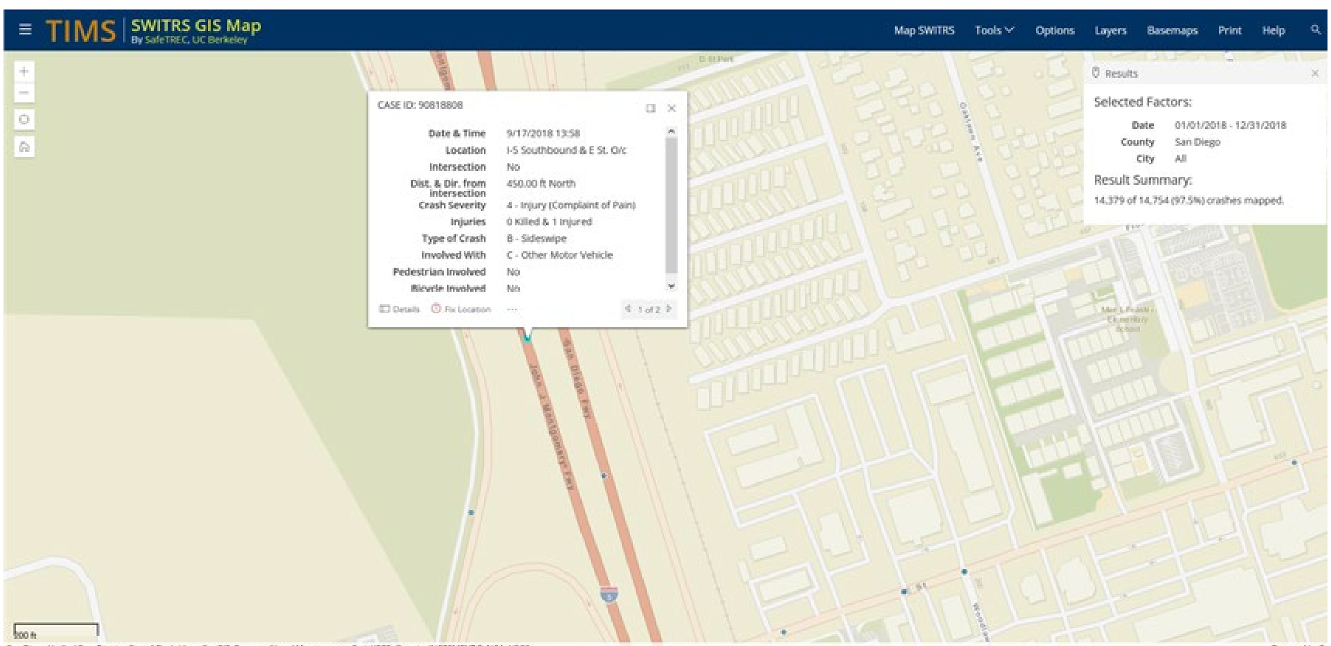

Figure 43. California crash data example.

PENNSYLVANIA

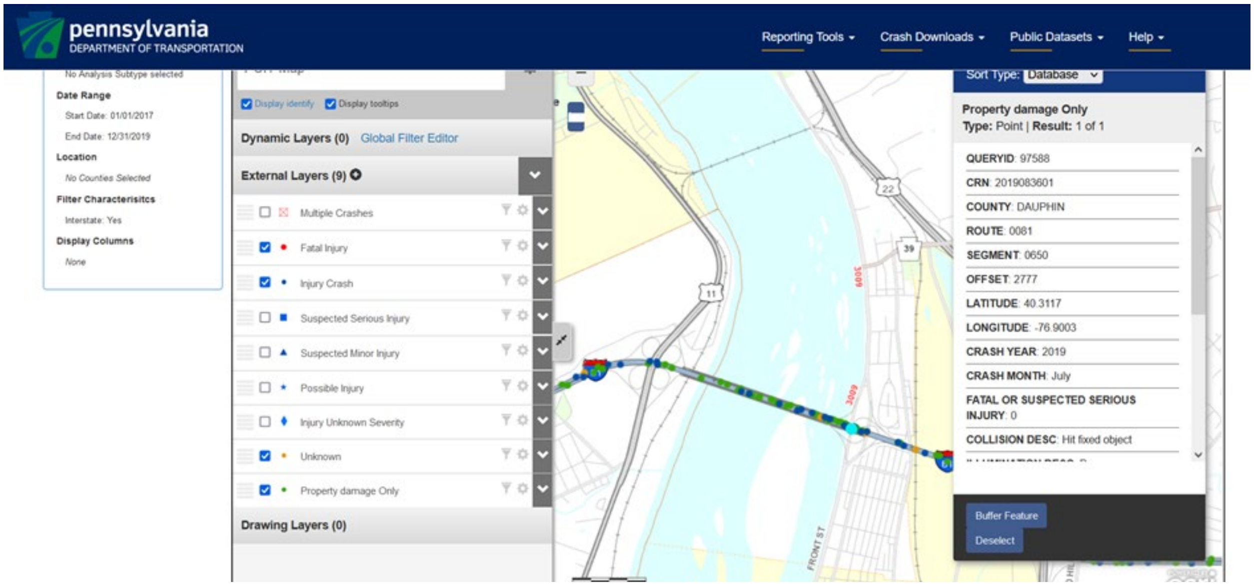

Figure 44. Pennsylvania crash data example.

APPENDIX F: BENEFIT-COST TOOL EXAMPLE

IDOT Benefit-Cost Analysis Tool for Contrast Pavement Markings
Input Sheet

Agency: Illinois Department of Transportation
Project Name: R27-223: CMFs for Contrast Pavement Markings

User Input Value	(yellow)
Suggested Value	(blue)
Calculated Value	(green)

Road Segment Characteristics	***User Input Value***	***Suggested Value***	***Unit***
Road ID	I-57		
County	Williamson County		
Average Speed Limit	65	65	mi/hr
Number of Lanes	6 6	4, 6 or 8 lanes	Lanes both directions
Mile Maker (MM) Start	70		
Mile Maker (MM) End	30		
Segment Length	40		Miles
Annual Average Daily Traffic (AADT)	60000		Veh/Day
Roadway Crash History	***User Input Value***	***Suggested Value***	***Unit***
Fatal (K)	1	3 to 5 year average	Crashes per year
Disabling Injury (A)	2	3 to 5 year average	Crashes per year
Evident Injury (B)	2	3 to 5 year average	Crashes per year
Possible Injury (C)	3	3 to 5 year average	Crashes per year
PDO (O)	15	3 to 5 year average	Crashes per year
Total Crashes	23	3 to 5 year average	Crashes per year
Benefit-Cost Analysis Inputs	***User Input Value***	***Suggested Value***	***Unit***
Analysis Period	8	5 to 8 years	Years
Discount Rate	3%	3%	%
Inflation Rate	3%	Yearly increase from base year (2022)	%
Year of Study	2022		
Project Costs	***User Input Value***	***Suggested Value***	***Unit***
Contrast Pavement Markings	$ 3.50	$ 3.50	Cost per 40 feet of lane line
Contrast Pavement Markings (cost per lane line)	$ 18,480.00		Cost per lane line
Standard Tape Markings	$ 1.75	$ 1.75	Cost per 40 feet of lane line
Standard Tape Markings (cost per lane line)	$ 9,240.00		Cost per lane line
Itemized Costs (Contrast Markings)			
Installation Cost	$ 73,920.00		
Annual Maintenance Cost	$ -		
Itemized Costs (Standard Tapes)			
Installation Cost	$ 36,960.00		
Annual Maintenance Cost	$ -		
Itemized Annual Benefits			
Fatal (K)	$ 522,041.48		
Disabling Injury (A)	$ 56,255.31		
Evident Injury (B)	$ 20,574.79		
Possible Injury (C)	$ 17,540.78		
PDO (O)	$ 26,844.15		
Total	$ 643,256.51		
Estimated Number of Crash Reductions per Year			
Fatal (K)	0.07		
Disabling Injury (A)	0.14		
Evident Injury (B)	0.14		
Possible Injury (C)	0.21		
PDO (O)	1.80		
Total	2.76		
Benefit-Cost Analysis Results			
Present Value Cost ($) Contrast Markings	$ 73,920.00		Installation and annual costs
Present Value Benefits ($) Contrast Markings	$ 4,515,462.70		Annual benefits over life (n)
Benefit-Cost Ratio (Contrast Markings)	61.1		
Present Value Cost ($) Standard Tapes	36960.0		
Benefit-Cost Ratio Between Contrast and Standard	122.17		
Project Feasibility	Feasible		

Note: For 4 Lane sections only PDO data is available due to limited locations and few fatal/injury crashes.
Note: The calculations show the benefits and reductions in roadway departure crashes.

Figure 45. Image. Benefit-cost tool example.

Illinois Department of Transportation

ILLINOIS