Safety Benefit Analysis of Alternative Delineation Practices in Michigan

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SAFETY BENEFIT ANALYSIS OF ALTERNATIVE DELINEATION PRACTICES IN MICHIGAN

by

Brenda C. Burdick

A thesis submitted to the Graduate College
in partial fulfillment of the requirements
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Among the many aspects of roadway design, one important system is roadway delineation. The main purposes of roadway delineation include regulating, warning, and guiding drivers in a safe manner. Delineation systems have the potential to reduce crashes. This research sought to perform safety benefit analysis of roadway delineation practices in Michigan. Through literature review, several delineation practices, selection criteria, and previously developed crash modification factors were researched. Even though several pavement marking materials have been implemented in Michigan, a safety benefit analysis of various materials had not been performed. Sites were selected, and pavement marking material inventory data were combined with crash data. Statistical modeling was completed in order to determine if one material had any safety benefit over the others. It was determined that polyurea had the potential to reduce crashes on segments that currently have waterborne paint implemented. Additionally, it was determined that it would be beneficial to identify other states’ delineation practices and the criteria used to determine when implementation was appropriate. A survey was completed and resulted in the participation of 20 states in the U.S. and two provinces in Canada. Cost-benefit analysis was also performed to identify the cost savings if polyurea were to be implemented wherever there was waterborne paint. Additionally, snowplowable raised pavement markers, which are not currently implemented in Michigan, were analyzed through cost-benefit analysis to identify the impact they would have if they were implemented in Michigan based on previous research and developed crash modification factors.
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All glory belongs to God.

Brenda C. Burdick
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CHAPTER I

INTRODUCTION

Innovation is essential to moving technology forward. The same is true for transportation engineering. It is imperative to continue seeking the best practices in order to provide the best and safest services possible. This fact is also amplified in that the chosen countermeasures directly affect the safety of everyone using a facility.

Delineation is an essential part of roadway design. It provides guidance and seeks to minimize potentially dangerous scenarios. Traffic accidents occur frequently, many of which could be influenced by delineation systems. The frequency of specific crash types such as those involving lane departures or nighttime conditions could be reduced by the implementation of appropriate roadway delineation countermeasures.

Research Problem and Objectives

Thousands of individuals are impacted by traffic accidents every year. Due to their direct impact on the safety and usability of a facility, roadway features have the ability to increase or decrease an individual’s risk of being involved in an accident. In order to promote the safety of road users, it is imperative to choose appropriate delineation systems. However, a lack of crash modification factors (CMFs) exists for specific pavement marking materials. Additionally, uniform decision criteria for deciding on implementation across jurisdictions are not readily available. The state of Michigan has specific marking materials that are implemented in addition to other delineation systems. It is important to evaluate the performance of the current systems in order to assess the need for the implementation of alternative methods.

The main objective of this research was to perform safety benefit analysis of roadway delineation practices in Michigan. This goal was accomplished by first identifying several delineation practices, selection criteria, and previously developed crash modification factors.
through literature review. Then, data-driven analysis was completed to identify safety benefits of implementing alternative pavement marking materials. Sites were selected, and pavement marking material inventory data were combined with crash data. Additionally, a survey was performed to identify other states’ delineation practices and the criteria used to determine when implementation was appropriate. Finally, cost-benefit analysis was also performed to identify the benefit of cost savings due to a reduction in crashes based on the application of crash reduction factors (CRFs) while also factoring in additional installation costs for alternative delineation systems.

Scope of Research

In regard to delineation, the process of decision-making is aided by CMFs that predict the impact that a specific system will have on the number of crashes. Upon completion of a literature review, it was noted that most delineation systems already possessed CMFs to predict their effect on the number of crashes. However, it was also noted that there were not CMFs developed for specific pavement marking materials. Due to this deficit, crash modification factors were developed for different marking materials that are implemented in the state of Michigan. Upon development, CMFs for selected delineation systems were then used in cost-benefit analysis in order to fully encapsulate the elements that would determine if one system is superior to another and the factors to be considered upon its implementation.

Additionally, a survey on delineation practices was performed in order to gather information about what other states and provinces implement in terms of delineation as well as the criteria that they use to determine when implementation is appropriate. Life span, unit costs, and marking material alternatives were also captured.
CHAPTER II

LITERATURE REVIEW

Introduction

In order to fully define and understand current and potential delineation practices, a literature review was conducted. Delineation is defined by the Federal Highway Administration (FHWA) as any method that defines the roadway operating area for the driver. Requirements for such practices are included in the Manual on Uniform Traffic Control Devices (MUTCD).

An additional resource detailing delineation practices is the Roadway Delineation Handbook that aids in the decision-making and maintenance processes of roadway delineation systems. It concludes that roadway delineation is a crucial component of several aspects of transportation including traffic flow, driver comfort, and traffic safety. Delineation systems are defined as devices that regulate, warn, and guide drivers. It is noted that warning signs are considered a delineation system while guide signs are not included.

An important factor of delineation is retroreflectivity. Adequate levels are achieved by glass beads or prismatic cube-corner retroreflection. Glass beads are typically dropped on or premixed in a pavement marking material while prismatic cubes are applied to raised pavement markers (RPMs). Prismatic sheeting is also implemented as post-mounted delineator buttons.

Delineation must be able to accommodate all types of environmental conditions as well as drivers. Environmental factors that may impede delineators include darkness as well as adverse weather conditions such as fog and precipitation. Additionally, drivers may have vision deficiencies due to age or intoxicants. Visibility is defined by several criteria including luminance, contrast, conspicuity, and legibility. Also, a driver’s visibility of a delineator is not only impacted by their physical ability to see such a device but also their ability to view, understand, and interpret the perceived guidance.
Delineation Systems

Since many different instances require guidance, multiple delineation systems exist to best accommodate certain circumstances. Delineators typically fall into one of two categories, short range or long range delineation in terms of viewing distance. Short range delineation was determined to require a preview time of up to three seconds while long range delineation was defined as possessing a preview time of at least five seconds (Rumar & Marsh, 1998). In this literature review, short range delineation encompasses pavement markings as well as rumble strips among others. Long range delineation consists of lighting, alignment signs, and reflectors. Other delineation systems researched include painted shoulders or medians, warning signs, barrier delineators, and pavement symbols.

Short Range Delineation

Short range delineation, including longitudinal pavement markings, are an important function used to guide and inform road users. Appropriate materials will maintain their specified color throughout their lifespan; consideration is also given when a material is prone to reducing traction for drivers (MUTCD, 2009).

Michigan implements a maintenance plan that mandates the annual restriping using either waterborne paint or sprayable thermoplastic (STP). The annual application of these materials does not consider any factors, e.g. traffic volume. Even though the majority of Michigan Department of Transportation (MDOT) maintained roadways possess one of these materials, other materials have been considered and implemented on a limited basis.

Most pavement markings are commonly considered as nondurable and durable. Nondurable markings include paints while durable markings consist of epoxy, thermoplastics, polyurea, modified urethane, and preformed tapes. The aforementioned materials have unique
characteristics regarding service life, quality of color, retroreflectivity, application methods, and unit cost (Iowa Traffic Control Devices and Pavement Markings, 2001).

Short range delineation is not limited to pavement markings. Other delineation systems considered short range include special pavement markings and rumble strips.

**Pavement Markings**

Specific characteristics regarding application methods, service life, and retroreflectivity for different types of pavement marking materials were assessed and summarized as follows.

*Painted markings.* Painted markings have many applications including lane lines, centerlines, edge lines, crosswalks, and stop bars. They have also been used to denote areas to avoid, such as gores, islands, and medians. The three most important elements of painted marking systems include the paint itself, reflective beads, and the pavement surface. Additionally, paint is classified by its retroreflectivity, method of application, and drying time. Painted markings most often experience failure resulting from loss of substance due to abrasion, cohesive failure within the paint, or adhesive failure with the pavement surface (MUTCD, 2009)

*Thermoplastic materials.* Due to their increased durability and long-term impact, thermoplastics are often implemented as an alternative to painted markings. Typically, the break-even point for thermoplastics is three to seven years. Thermoplastic materials have been highly rated by many highway agencies. The basic components include binder, pigment, and glass beads. The binder, either alkyd-based or hydrocarbon-based, often classifies thermoplastics.

*Preformed tapes.* Cold-applied preformed plastic tape markings are supplied in continuous rolls by specific length and widths. This type of marking is most often implemented as stop bars, crosswalks, words, and symbols among other specialized treatments. In areas with low traffic volumes, they may be applied as centerlines or lane lines. It has been found that tapes
perform better on asphalt pavement surfaces rather than concrete. Preformed tapes have applications limited to urban locations due to high costs and reduced reflectivity over their service life.

*Other marking materials.* In addition to the aforementioned pavement marking materials, alternative paints and durable markings have been implemented in other jurisdiction. These alternatives include latex paint, epoxy paint, polyester, epoxy thermoplastic, methyl methacrylate, and marking powder among other materials.

In addition to alternative materials, there are also alternative methods of implementing pavement markings. Areas that require winter maintenance may experience reduced service life and degraded retroreflectivity of marking materials due to damage from snowplow blades. It has been found that recessing any marking material will increase the service life due to protection from snowplow damage. A study was completed in Japan to analyze the best materials for recessed markings. It was found that waterborne paint might not be the most suitable for the recessing process. Therefore, it was proposed that STP and other durable markings might be more appropriate. Additionally, it was recommended that highly reflective materials be used with recessed markings. Visibility of recessed markings may be impeded during adverse weather due to the inlaid areas that contain the markings filling with rain or snow (Hirasawa, et. al., 2010).

**Special Pavement Markings**

Used to enhance short range delineation, special pavement markings include raised pavement markers (RPMs), wider pavement markings, and contrast tapes.

It is often noted that pavement markings are not visible when roadways become wet during nighttime hours. In order to maintain visibility during such conditions, pavement markings may be supplemented by RPMs. The implementation of RPMs is most applicable in areas that require potentially hazardous actions such as exit ramps, bridge approaches, lane transitions, and
horizontal curves. The main deterrent towards RPMs is the possibility of damage from snowplow blades in areas requiring winter maintenance. The method of adhesive application is critical to the performance and durability of RPMs. Factors affecting the pavement bond include properties of the adhesive, design of the RPMs bonding surface, pavement surface, temperature, and care in application. In special circumstances, RPMs may replace other markings (MUTCD, 2009).

For areas that require snow removal and winter maintenance, snowplowable raised pavement markers (SRPMs) are an option. A study surrounding the safety impact of SRPMs was performed when they were randomly and selectively implemented. SRPMs did not have a conclusively significant impact when they were randomly implemented. However, when traffic volume and road geometry were considered, different results were obtained. It was found that low volume two-lane roads could experience a negative impact from RPMs. However, four-lane freeways showed a significant reduction in wet weather and nighttime crashes when the annual average daily traffic (AADT) exceeded 20,000 vehicles per day (Bahar, et. al., 2004). Similarly, a study in Alberta, Canada concluded that SRPMs continued to perform well along a centerline throughout five years of use (Filice, 2006).

Longitudinal pavement markings wider than the minimum required four-inch standard are considered wider markings. Research by the Texas Transportation Institute (TTI) assessed the impact of implementing six-inch wide edge lines on rural two-lane highways. Data that was analyzed included driver opinions, vehicle operations, and visibility as well as crash data. Their results indicated that wider pavement markings have the potential to reduce total crashes by 15 to 30 percent as well as a reduction in fatal and injury crashes of 15 to 38 percent (Carlson & Wagner, 2012).

**Contrast Markings**

In Michigan, contrast markings are typically implemented on new concrete roads. However, they are currently in limited use. Two types of contrast markings exist, bordered design
and shadow design. Bordered contrast markings consist of a white marking that is highlighted with black markings along the longitudinal sides while the shadow design involves a white marking that is followed or preceded by a black marking.

Research was conducted by the state of Texas to evaluate both types of contrast markings. It was noted that some drivers were confused by contrast markings. Additionally, it was found that drivers prefer bordered markings while the shadow design may be more cost effective. No safety analysis was completed. However, a consensus was reached that contrast markings provide better contrast and visibility on Portland cement concrete road surfaces (Carlson, et. al., 2012).

**Rumble Strips**

In addition to pavement markings, rumble strips are also considered short range delineation. Rumble strips may be applied in a variety of location including on the centerline, shoulder, or edge line. The Federal Highway Administration identifies rumble strips as a countermeasure that has been proven to reduce roadway departure crashes. It is suggested that rumble strips be implemented on all roadways that possess a speed limit of 50 mph or greater. Additionally, they should be considered for areas that experience a high proportion of road departure crashes regardless of area type (Technical Advisory, 2011). A crash reduction for the application of shoulder and centerline rumble strips was calculated to be between 11 percent and 51 percent depending on the road type and injury severity (Torbic, et. al., 2009).

**Long Range Delineation**

Long range delineation are especially effective at providing guidance during adverse weather and nighttime condition when other short range delineation may be inhibited. Such delineation systems provide effective guidance when road alignment becomes confusing and include lighting, alignment signs, and post-mounted delineators.
**Lighting**

The main benefit of lighting is that it improves visibility of the roadway and potential obstacles while increasing sight distance. The implementation of lighting is determined by several key factors including traffic volume, spacing of freeway interchanges, lighting in adjacent areas, and night-to-day crash ratio (AASHTO, 2005). Additional factors that may also be considered include geometry, operation characteristics, environmental factors, and crash rates (TAC, 2006).

Many studies have concluded that lighting helps reduce crashes. Additional studies have been conducted to analyze the difference between light emitting diode (LED) applications and traditional high pressure sodium lamps. One such study determined that the LED had a more ‘white’ appearance than traditional options. Overall, both types of lighting performed similarly with LED implementation resulting in a reduction in overall system costs of 15 percent (Bullough & Radetsky, 2013).

**Alignment Signs**

Typically, alignment signs consist of chevrons, horizontal arrows, and advance warning signs. A study was conducted by the FHWA to assess the safety effectiveness of improved curve delineation along two-lane rural roads. In addition to implementing the aforementioned alignment signs, improved fluorescent yellow sheeting was also investigated. Findings include a reduction in fatal and injury crashes of 18 percent and a reduction in nighttime crashes of 27.5 percent. These reductions were further amplified in areas with a high traffic volume and low radius of curvature. Signs that were improved with higher retroreflective sheeting also had a significant impact. Overall, improving horizontal curve delineation proved to be cost-effective (Srinivasan, et. al., 2009).

Chevrons are an effective way to provide advance warning and positive guidance in areas with horizontal curves. A study was conducted to assess the impact of chevron signs on vehicle speed and positioning between lane lines. Two different chevron designs were tested including
standard chevrons and chevrons with retroreflective posts. Little difference was established between the two designs. When compared to no chevron implementation, findings include vehicles shifting away from the centerline by an average of 15 inches and a reduction of speed between 1.25 and 2.20 mph (Re, Hawkins, & Chrysler, 2010).

Further innovations in alignment signs have been experienced. Dynamic Curve Warning and Guidance Systems are another chevron treatment that involves the use of LED lights that outline the shape of the chevron and flash in a sequential manner. Advantages of this system have been assessed and include a reduction in speed-related, head-on, cross-median, and roadway departure crashes (TAPCO, 2016).

**Post-mounted Delineators**

Post-mounted delineators have been noted to provide better delineation during adverse weather and nighttime conditions compared to pavement markings. Additionally, post-mounted delineators are used to enhance the edge of the roadway and accent critical locations. Typical installation involves a delineator being placed 4 feet above the surface of the pavement surface and have a visible distance of 1,000 feet (305 meters) when illuminated by vehicle headlights. The minimum dimension of the retroreflective element is 3 inches (MUTCD, 2009).

In the state of Michigan, two types of post-mounted delineators are installed. The different designs are categorized by the type of post, which include rigid steel and flexible posts. Flexible posts have been implemented due to the fact that they are designed to withstand multiple impacts unlike rigid posts. Additionally, flexible posts reduce the amount of damage caused upon impact with a vehicle and potential injury when compared to rigid posts. However, other states have completed studies due to the excessive replacement of flexible post delineators resulting in higher life-cycle costs (Siddharthan, Fine, & Dennett, 2003).

A survey was conducted to identify and evaluate the use of flexible delineators among several states. Of the 11 states that responded, three states reported the use of flexible delineators
in right-of-way applications. Three states also stated advantages of using flexible delineators over rigid, which include resilience to impact, less damage upon impact, less maintenance, and longer service life. Disadvantages include a higher initial cost and susceptibility to destruction by summer and winter maintenance. Finally, several states reported the use of reflective tape or sheeting with comparable or better visibility than traditional prismatic reflectors (CTC & Associates, 2007).

Another study was conducted to analyze the impact of the implementation of standard post-mounted delineators with a single reflector and fully retroreflective post-mounted delineators. Findings include a uniform improvement in vehicle lane positioning and a reduction in encroachment across both systems. However, the fully retroreflective post-mounted delineators performed slightly better (Chrysler, et. al., 2009).

Other Delineation Systems

In addition to the aforementioned delineation systems, other delineation systems have been implemented in other jurisdictions. These alternative systems include colored shoulder pavement, gateway treatments, and painted medians.

Research was completed in order to analyze the effect of colored shoulders on vehicle speed. Results from this study showed that colored shoulders had minimal effect with a slight increase in speeds for trucks (Orr, Stein, & Lampman, 2015). Another application of painted shoulders is as a component of gateway treatments that have been implemented in Europe. These features provide visual cues to signify the transition into a different area. For example, gateways have been used on highways and county roads that transition to roads with lower speed limits throughout rural communities. Such systems were implemented in Iowa; research was conducted to evaluate the use of gateways that used signage, lane reduction, colored pavements, pavement
markings, and gateway structures in addition to traditional traffic calming techniques. Some of the elements in the systems were shown to reduce speed (Hallmark, et. al., 2007).

Another alternative system, painted medians, was evaluated on a rural undivided highway in Australia. The painted median was one-meter wide and included rumble strips. Results from the study showed that there was a reduction in total crashes of 59 percent and head-on crashes of 75 percent (Whittaker, 2012).

**Selection Criteria**

Due to the availability of many different delineation devices, it is important to establish criteria and influential factors when making uniform decisions about delineator implementation. These factors typically include geometry, pavement surface, weather, traffic conditions, and human factors. Other factors are considered but do not have literature to indicate that they are a significantly influential factor. These other criteria include lighting, speed, and roadway functional classification.

**Roadway Geometry**

Due to the inconsistent nature of roadway environments, roadway geometry may vary greatly. Examples of different geometry include straight sections, horizontal curves, areas with changes in lane width, and merging or diverging areas.

Many studies have researched the effects of centerline and edge line implementation. Most point to reduced crashes upon the implementation of such measures. However, it should be noted that research shows that edge lines increase the potential of head-on collisions; this fact is due to drivers aligning with the centerline rather than the edge of the roadway in the presence of edge lines. Because of this finding, many states have established a minimum width of 18 feet for implementing edge lines (Migletz, Fish, & Graham, 1994).
Horizontal curves often require enhanced delineation. The radius of curvature is conveyed through the difference in posted speed limit and advisory speed. This difference is used as an indicator of the type of delineation that is necessary. Recommended types of delineation include advisory speed plaque, chevrons, and exit and ramp speeds among others (MUTCD, 2009).

**Pavement Surface**

The type of pavement surface often dictates the type of painted marking as well as the durability and life span. Additionally, the remaining service life of the pavement is important when considering durable pavement markings such as thermoplastic or supplementary markings such as RPMs.

A study was conducted by TTI in order to determine best practices for pavement markings on concrete roadways. Specific measures that were considered include durability, retroreflectivity, and contrast. Findings include the best material for long-term applications under the majority of traffic conditions was epoxy while very heavy traffic would be accommodated by preformed tape markings. Additionally, thermoplastic markings should only be used for short-term applications with low to medium traffic (Gates, Hawkins, & Rose, 2003).

**Weather and Climate**

Weather and climate are important factors due to the change in driver behavior that they may impart and the reduced durability due to roadway maintenance. Research completed in New Zealand evaluated differences in driver behavior under different roadway environments such as dry daytime, wet, or nighttime conditions. Perceived risk was measured through observance of the speed, headway, and hand position. Findings include an elevated perceived risk when compared to dry or nighttime conditions. Wet road conditions also resulted in reduced speed. Thus, priority should be placed on wet conditions rather than nighttime (Walton, et. al., 2011).
Based on the findings in the previous study and others, roadway delineation must accommodate all weather conditions, especially the adverse. Specific delineators, such as post-mounted, RPMs, and marking materials with reflective beads, have shown to have increased visibility especially during adverse weather.

**Traffic Composition**

Traffic volume is often a key factor when considering what material to implement for pavement marking application. Roads with higher traffic volumes or elevated proportions of heavy vehicles have shown to reduce the service life of marking materials and should be considered for the application of more durable markings. The FHWA handbook describes the correlation between traffic volume (AADT) and service life of pavement markings (Migletz, Fish, & Graham, 1994).

**Human Factors**

Safe driver behavior is dependent on perception of a situation, level of alertness, and application of available information. Due to the majority of these factors resulting from visual cues, it is important to recognize the challenge faced by drivers with greater visibility needs, including older drivers. To accommodate drivers with limited vision, increased visibility and supplemental delineation may be necessary to convey appropriate information (Migletz, Fish, & Graham, 1994). Older drivers require brighter delineation and longer reaction times. Pavement markings alone may not fully accommodate all drivers at all speed levels. Therefore, supplemental delineation such as RPMs may be warranted to accommodate most drivers (Migletz & Graham, 2002).
Crash Modification Factor Development

Due to the necessity of delineation, it is also important to understand the safety impact that such delineation systems will impart. Studies have been completed to show the impact that delineators have through the development of CMFs.

One such study performed by Sun and Das to evaluate the addition of edge lines to rural two-lane highways. The study found that vehicles were more likely to remain positioned in the middle of the lane in the presence of edge lines, therefore reducing the amount of lane departure crashes. Statistical analysis was completed and modeling was done using before/after with empirical Bayes method. The study found that the addition of edge lines could reduce crashes by 17 percent with a CMF that was calculated to be 0.83 (Sun & Das, 2012).

Another study was completed by TTI that investigated the effects of implementing wider edge lines on two-lane, rural highways. Due to a lack of convincing evidence of their effectiveness, the safety benefit of wider edge lines was evaluated through statistical analysis. Several methods were used to develop CMFs for individual states. A generalized linear segmented regression analysis was completed to analyze Michigan data. Overall, it was determined that the implementation of wider edge lines had the potential to reduce crashes with a CMF of 0.825 (Park, et. al., 2012).

Additionally, research performed in Korea to analyze the effect of ten different freeway elements including post-mounted delineators. The analysis to determine the safety effect was completed using the empirical Bayes method. In the end, it was found that post-mounted delineators may in fact increase the crash rate with a developed CMF of 1.19 (Choi, et. al., 2015).

As previously detailed, Srinivasan, et. al., evaluated the safety impact of certain horizontal curve delineators. Their research determined that the implementation of chevrons could reduce crashes, which is represented by a CMF of 0.78 (Srinivasan, et. al., 2009).
In the aforementioned study on the effects of centerline and shoulder rumble strip implementation, CMFs were developed using the empirical Bayes method. A CMF of 0.91 was calculated for the implementation of centerline rumble strips showing a reduction in total crashes. Additionally, shoulder rumble strips were found to reduce single-vehicle run-off-road crashes on rural freeways with a CMF calculated to be 0.89. Additionally, crash types and conditions were also analyzed in this study (Torbic, et. al., 2009).

As previously mentioned, a study performed by Bahar, et. al., evaluated the effect of implementing SRPMs. Using an empirical Bayes before-after study, CMFs were developed. It was found that implementation of SRPMs had the potential to cause a significant reduction in nighttime crashes. The CMFs for nighttime were calculated to be 0.94 for areas with an AADT between 20,000 and 60,000 and 0.67 for areas with an AADT greater than 60,000 (Bahar, et. al., 2004).
CHAPTER III

STATISTICAL MODELING

Methodology

Several methods of analysis were utilized in order to complete this analysis. Site selection and statistical modeling were completed based on alternative painted markings.

Site Selection

In order to complete the statistical analysis, it was necessary to select a group of sites on which to perform the necessary calculations. Due to limited implementation, all sites containing modified urethane, tape, and polyurea were selected. In order to develop a selection of STP and waterborne paint that was the best representation of the total data set, a selection was made based on the national functional class, population group, pavement surface material, and AADT. This data was added from MDOT sufficiency files that detail characteristics of all MDOT-maintained roadways. Once the sites were arranged in combinations of the selected parameters, a percentage of each combination was selected in order to maintain the proportion among the parameters.

One challenge with this analysis was compiling complete sets of data. Guardrail location data was obtained through MDOT. However, two regions (5 and 6) were not included in the inventory. Therefore, these regions were excluded from the data selection.

Statistical Modeling

Crash-frequency data analysis is typically done with models that can appropriately accommodate the specific type of data being used. A negative binomial regression was used since the data consisted of non-negative integers.

The Poisson regression is typically used for such analysis. Additionally, the Poisson regression is a subcategory of negative binomial regression and requires the mean and variance to
be equal. With this method, the probability of a section of roadway, \( i \), experiencing a certain number of crashes, \( y_i \), within some time period is predicted by

\[
P(y_i) = \frac{\exp(-\lambda_i) \lambda_i^{y_i}}{y_i!}
\]

where \( P(y_i) \) is the probability of having \( y_i \) crashes on a roadway section \( i \). Additionally, \( \lambda_i \) is the Poisson parameter for a specific roadway section \( i \) and equals the number of crashes expected in a year. Typically, the Poisson parameter is calculated as

\[
\lambda_i = \exp(\beta X_i)
\]

where \( \beta \) is a vector of estimable coefficients and \( X_i \) is a vector of explanatory variables.

However, as mentioned previously, a Poisson regression was not appropriate for this analysis. Therefore, a different parameter had to be calculated. For a negative binomial regression, the Poisson parameter becomes

\[
\lambda_i = \exp(\beta X_i + \epsilon_i)
\]

where \( \exp(\epsilon_i) \) is a gamma-distributed error term that possesses a mean of one and a variance equal to \( \alpha \). Inclusion of an error term allows for the mean and variance to differ.

This analysis was then accomplished using STATA computational software. Notable output of the modeling includes a coefficient, \( C \), and estimated \( z \)-value. The \( z \)-value is used to estimate the significance of the impact that a variable would cause. Variables were included if they had a significant \( z \)-value greater than 1.64 with 90 percent confidence.

Upon the completion of statistical modeling, crash modification factors were developed from the results of the model. A cross-sectional method was used to develop the CMFs due to unknown dates of implementation for the different delineation systems. The cross-sectional method results in CMFs calculated by

\[
CMF_i = \exp(C_i V)
\]
where \( C \) is the coefficient of variable \( i \) while \( V \) is the value necessary to apply the CMF. In this case, the CMF will be used to estimate a unit change; therefore, \( V \) was set equal to one.

Additionally, a CRF can be calculated by

\[
CRF = 1 - CMF
\]

While the cross-sectional method is allowed for the calculation of CMFs, it is not perfect and has some disadvantages. The main drawback to using this method is the effect that variables that are excluded may have. Whether they are known or unknown, the exclusion of variables may have a significant impact on the model. Additionally, the sample size dictates the number of variables that can be included in the model (Lord & Mannering, 2010).

Data

Due to the nature of data-driven analysis, acquiring and arranging an accurate data set is essential to the outcome of the analysis. The bulk of the analysis centered on developing CMFs for alternative pavement marking materials. Necessary data included pavement marking material inventory data and crash data. From these datasets, variables were selected for statistical modeling. The following sections detail the data used and provide descriptive statistics.

Pavement Marking Material Inventory Data

The pavement marking material inventory was acquired from MDOT. The long line inventory specified locations and the marking material used. As previously described, only a selection of sites were used in the analysis for STP and waterborne paints while all of the sites containing modified urethane, tape, and polyurea were included. The following paragraphs describe the data for all sites as well as the selected sites.
All Sites

In total, 2,526 sites were included in the long line painted marking inventory. These sites were categorized by the marking material that was implemented within the site. In some cases, multiple materials were implemented. Figure 1 details the overall distribution of the total sites by the material implemented. Over half of the sites contained STP while just over 40 percent of the sites included waterborne paint. Polyurea, modified urethane, and tape make up the smallest three proportions with all three materials making up less than three percent of all sites. Figure 2 shows all sites based on their location as detailed in the inventory. Sites are shown in different colors based on the material that was implemented.

![Diagram showing marking material distribution]

*Figure 1 Distribution of marking material implementation for all sites.*
Figure 2 All sites in marking material inventory based on marking material.
Selected Sites

In order to perform comprehensive analysis, it was essential to pick a selection of some of the sites. Due to their already small sample size, all sites that contained modified urethane, tape, or polyurea were included in the selection. Therefore, the selection process was used to choose sites where STP or waterborne paint were implemented. As previously discussed, measures were taken in order to ensure that the selection made would be an accurate representation of the total data. Factors that were considered include national functional class, population, pavement surface material, and AADT. Additionally, all sites within Regions 5 and 6 were not considered due to a lack of guardrail inventory data.

Of the total 2,526 sites, 286 sites were selected for this analysis. Additionally, Figure 3 shows the distribution of marking materials among the selected sites. Waterborne and STP still contribute to the largest proportions of sites with 43 and 30 percent, respectively. All sites containing tape, polyurea, or modified urethane that were not removed due to lack of information were included in the selection to account for 27 percent of the 286 selected sites. The locations of the selected sites are shown in Figure 4. Sites are shown in different colors that correspond with the implemented material.

![Figure 3 Distribution of marking materials among selected sites.](image-url)
Figure 4 Selected sites from marking material inventory based on marking material.
Additional attributes were added based on inventories acquired from MDOT. These inventories included the locations of key features such as recessed markings, rumble strips, and guardrails. Figure 5 shows the number of selected sites based on the implementation of these features. Most sites do not have recessed markings or rumble strips with only 33 sites having recessed markings implemented and 59 sites possessing rumble strips of the 286 selected sites.

![Recessed, Rumble Strips, Guardrail Locations (Selected Sites)](image)

*Figure 5 Frequency of recessed, rumble strip, and guardrail locations within the selected sites.*

**Crash Data**

To measure the safety impact of transportation systems, it is essential to investigate relevant crash data. The following sections show the crash data for the entire state of Michigan. In addition, only crash data associated with selected sites is discussed. Crash data was used from 2013 and 2014 in conjunction with 2013 inventory data. Two years of crash data were required to increase the sample size to aid in statistical modeling and CMF development.

**Total Crash Data**

In the entire state of Michigan, 296,290 total crashes were recorded in 2013. Additionally, 306,306 total crashes were experienced in 2014. Of these crashes, several different lighting conditions were recorded. Figure 6 shows the distribution of total crashes from 2013 and...
2014 by lighting condition. The majority of crashes occurred during daylight conditions followed by dark-unlighted and dark-lighted.

![Figure 6: Frequency of total crashes by lighting condition and year.](image)

Another important factor to consider when addressing road delineation is crashes involving lane departures. Since one of the purposes of road delineation is to guide the driver on the safest path possible, it is ideal that delineation systems would reduce the number of crashes involving a lane departure. Figure 7 shows the distribution of total crashes by the type of lane departure. The majority of crashes did not include a lane departure. However, the majority of crashes that did include a lane departure involved a single vehicle.
Figure 7 Frequency of all crashes by lane departure and year.

Figure 8 depicts the proportion of departure-involved crashes by lighting condition at the time of crash occurrence. Departure-involved crashes include all three categories depicted in Figure 7. Elevated proportions of departure-involved crashes were noted for dark-lighted and dark-unlighted conditions when compared to the other lighting conditions. This finding supports the objective of reducing nighttime crashes.

Figure 8 Proportion of departure-involved crashes by lighting condition for all crashes (2013-2014).
Selected Sites

In order to analyze the effect of different delineation systems, it was imperative to isolate areas around the selected sites and only select crashes within those areas. A buffer of 30 feet on either side was used to spatially locate crashes that were associated with the selected sites; these crashes were then compiled into a set of crash data. In addition, it was noted that intersection crashes were the least likely to be influenced by delineation systems. Therefore, it was determined that any crashes involving an intersection would be removed when compiling crash data for the selected sites. Within the 286 selected sites, there were 3,458 crashes experienced in 2013 and 3,583 crashes recorded in 2014.

![Lighting Condition (Selected Sites)](image)

*Figure 9 Frequency of crashes in selected sites by lighting condition and year.*

The distribution of crashes for the selected sites concerning lighting condition is shown in Figure 9. The majority of the selected crashes occurred during daylight conditions followed by dark-unlighted and dark-lighted. The statistical modeling focused on nighttime crashes, i.e. dark-unlighted and dark-lighted crashes, in order to evaluate the performance of delineation systems in low light conditions.

Concerning lane-departure involved crashes, Figure 10 shows the distribution of selected crashes by type of involved lane departure. As with total crashes, the majority of selected crashes did not involve a lane departure. The majority of departure crashes involved a single vehicle.
In Figure 11, the proportion of departure-involved crashes by lighting condition at the time of crash occurrence is shown. Similar to all crashes, an elevated proportion of departure-involved crashes were noted for dark-unlighted conditions when compared to the other lighting conditions. The further supports the emphasis on analyzing nighttime crashes.

*Figure 10 Frequency of crashes in selected sites by lane departure and year.*

*Figure 11 Proportion of departure-involved crashes by lighting condition for selected sites (2013-2014).*
Modeling Variables

The data used for the statistical modeling portion of the analysis was a combination of the previously described data. Additionally, data regarding the roadway characteristics were also incorporated. Table 1 details the variables that were utilized in the modeling analysis. The variable names are listed followed by a description and descriptive statistics.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
<th>Mean</th>
<th>Std Dev*</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>wtbn</td>
<td>Indicates implementation of waterborne paint</td>
<td>0.430</td>
<td>0.496</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>stp</td>
<td>Indicates implementation of sprayable thermoplastic</td>
<td>0.304</td>
<td>0.461</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>tape</td>
<td>Indicates implementation of cold or wet tape</td>
<td>0.042</td>
<td>0.201</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>poly</td>
<td>Indicates implementation of polyurea</td>
<td>0.108</td>
<td>0.311</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>mu</td>
<td>Indicates implementation of modified urethane</td>
<td>0.115</td>
<td>0.320</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>nfc_1</td>
<td>National Functional Class (NFC) indicator for arterials</td>
<td>0.969</td>
<td>0.175</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>nfc_2</td>
<td>National Functional Class (NFC) indicator for collectors</td>
<td>0.000</td>
<td>0.000</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>pop_1</td>
<td>Population group indicator, rural, less than 5,000</td>
<td>0.657</td>
<td>0.475</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>pop_2</td>
<td>Population group indicator, urban, greater than 5,000</td>
<td>0.343</td>
<td>0.475</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>surf_1</td>
<td>Surface type indicator, flexible</td>
<td>0.360</td>
<td>0.481</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>surf_2</td>
<td>Surface type indicator, rigid</td>
<td>0.238</td>
<td>0.426</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>surf_3</td>
<td>Surface type indicator, composite</td>
<td>0.402</td>
<td>0.491</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>length</td>
<td>Length of the segment, miles</td>
<td>1.630</td>
<td>2.253</td>
<td>0.055</td>
<td>21.74</td>
</tr>
<tr>
<td>surf_width</td>
<td>Width of the pavement surface, feet</td>
<td>32.50</td>
<td>13.32</td>
<td>16</td>
<td>86</td>
</tr>
<tr>
<td>num_lanes</td>
<td>Number of through lanes</td>
<td>2.552</td>
<td>0.945</td>
<td>1</td>
<td>6</td>
</tr>
<tr>
<td>lane_width</td>
<td>Width of through traffic lanes, feet</td>
<td>11.78</td>
<td>0.513</td>
<td>10</td>
<td>16</td>
</tr>
<tr>
<td>pass_lane</td>
<td>Indicates presence of passing lane</td>
<td>0.024</td>
<td>0.155</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>median_wid</td>
<td>Width of median for divided segments</td>
<td>24.90</td>
<td>48.12</td>
<td>0</td>
<td>550</td>
</tr>
<tr>
<td>spd_limit</td>
<td>Posted speed limit, miles per hour</td>
<td>52.75</td>
<td>14.05</td>
<td>25</td>
<td>70</td>
</tr>
<tr>
<td>pct_rstr</td>
<td>Percent of no-passing zone for the length of the segment</td>
<td>10.54</td>
<td>23.802</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>r_shdr_wid</td>
<td>Right shoulder width, feet</td>
<td>6.972</td>
<td>4.270</td>
<td>0</td>
<td>14</td>
</tr>
<tr>
<td>r_shdr_pvd</td>
<td>Width of paved right shoulder, feet</td>
<td>5.353</td>
<td>3.984</td>
<td>0</td>
<td>12</td>
</tr>
<tr>
<td>l_shdr_wid</td>
<td>Left shoulder width, feet</td>
<td>3.126</td>
<td>4.099</td>
<td>0</td>
<td>12</td>
</tr>
<tr>
<td>l_shdr_pvd</td>
<td>Width of paved left shoulder, feet</td>
<td>2.224</td>
<td>3.220</td>
<td>0</td>
<td>12</td>
</tr>
<tr>
<td>non_motor</td>
<td>Indicates presence of non-motorized facilities</td>
<td>0.070</td>
<td>0.255</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>aadt_1000</td>
<td>Annual average daily traffic, thousands</td>
<td>14.99</td>
<td>16.93</td>
<td>0.471</td>
<td>79.9</td>
</tr>
<tr>
<td>pct_comm</td>
<td>Percentage of traffic made up of commercial vehicles</td>
<td>5.248</td>
<td>3.803</td>
<td>1</td>
<td>32</td>
</tr>
<tr>
<td>signal_int</td>
<td>Indicates presence of one or more signalized intersections</td>
<td>0.311</td>
<td>0.464</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>gores</td>
<td>Indicates number of gores present</td>
<td>0.035</td>
<td>0.311</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>Variable</td>
<td>Description</td>
<td>Mean</td>
<td>Std Dev*</td>
<td>Min</td>
<td>Max</td>
</tr>
<tr>
<td>-------------------</td>
<td>--------------------------------------------------</td>
<td>-------</td>
<td>----------</td>
<td>-----</td>
<td>-----</td>
</tr>
<tr>
<td>recess</td>
<td>Indicates presence of recessed markings</td>
<td>0.115</td>
<td>0.320</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>rumble</td>
<td>Indicates presence of rumble strips</td>
<td>0.206</td>
<td>0.405</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>guardrail</td>
<td>Indicates presence of guardrails</td>
<td>0.559</td>
<td>0.497</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>total_13_14</td>
<td>Total crashes for the segment, 2013-2014</td>
<td>26.68</td>
<td>27.86</td>
<td>1</td>
<td>164</td>
</tr>
<tr>
<td>lit_night_13_14</td>
<td>Total crashes occurring at night, 2013-2014</td>
<td>7.850</td>
<td>7.911</td>
<td>0</td>
<td>44</td>
</tr>
<tr>
<td>dprt_any_13_14</td>
<td>Total crashes involving a vehicle road departure, 2013-2014</td>
<td>5.986</td>
<td>8.676</td>
<td>0</td>
<td>74</td>
</tr>
<tr>
<td>region_1</td>
<td>Indicates location in Region 1</td>
<td>0.318</td>
<td>0.467</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>region_2</td>
<td>Indicates location in Region 2</td>
<td>0.133</td>
<td>0.340</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>region_3</td>
<td>Indicates location in Region 3</td>
<td>0.157</td>
<td>0.365</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>region_4</td>
<td>Indicates location in Region 4</td>
<td>0.206</td>
<td>0.405</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>region_7</td>
<td>Indicates location in Region 7</td>
<td>0.185</td>
<td>0.389</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>terrain_level</td>
<td>Indicates areas with level terrain</td>
<td>0.850</td>
<td>0.358</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>terrain_rolling</td>
<td>Indicates areas with rolling terrain</td>
<td>0.150</td>
<td>0.358</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>median_typ_none</td>
<td>Indicates an undivided roadway</td>
<td>0.577</td>
<td>0.495</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>median_typ_concrete</td>
<td>Indicates roadway with a concrete median barrier</td>
<td>0.108</td>
<td>0.311</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>median_typ_guard</td>
<td>Indicates roadway with a guardrail in the median</td>
<td>0.014</td>
<td>0.118</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>median_typ_ditch</td>
<td>Indicates roadway with a ditch in the median</td>
<td>0.266</td>
<td>0.442</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>median_typ_curb</td>
<td>Indicates roadway with a curb as the median</td>
<td>0.035</td>
<td>0.184</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>sidewalk_0</td>
<td>Indicates no sidewalks present</td>
<td>0.748</td>
<td>0.435</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>sidewalk_1</td>
<td>Indicates sidewalk one side</td>
<td>0.115</td>
<td>0.320</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>sidewalk_2</td>
<td>Indicates sidewalk on both sides</td>
<td>0.136</td>
<td>0.344</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>ltd jt_end_ex</td>
<td>Indicates longitudinal joints in excellent condition</td>
<td>0.112</td>
<td>0.316</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>ltd jt_end_fair</td>
<td>Indicates longitudinal joints in fair condition</td>
<td>0.350</td>
<td>0.478</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>ltd jt_end_poor</td>
<td>Indicates longitudinal joints in poor condition</td>
<td>0.535</td>
<td>0.500</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>ltd jt_end_vrypoor</td>
<td>Indicates longitudinal joints in very poor condition</td>
<td>0.003</td>
<td>0.059</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>turn_lanes_none</td>
<td>Indicates no turn lanes present</td>
<td>0.490</td>
<td>0.501</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>turn_lane_left</td>
<td>Indicates presence of a left turn lane</td>
<td>0.122</td>
<td>0.328</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>turn_lane_right</td>
<td>Indicates presence of a right turn lane</td>
<td>0.105</td>
<td>0.307</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>turn_lanes_both</td>
<td>Indicates presence of both left and right turn lanes</td>
<td>0.283</td>
<td>0.451</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>

* Standard deviation
Results and Discussion

As previously discussed, negative binomial regression analysis was completed using STATA statistical software. Several factors were identified as having a significant impact. Significant factors in this model may have a positive or negative influence on the amount of resultant nighttime crashes. Initially, the model was run with all of the variables listed in Table 1 included. Variables that proved to be insignificant were removed in a systematic fashion until only significant variables remained. Table 2 shows the modeling results acquired from STATA.

\begin{table}
\centering
\caption{Statistical modeling results}
\begin{tabular}{|l|c|c|c|c|c|}
\hline
\textbf{Negative Binomial Regression} & Number of obs = 286 & LR chi2(20) = 201.91 & & & \\
Dispersion = mean & Prob > chi2 = 0 & & & & \\
Log likelihood = -748.16 & Pseudo R2 = 0.1189 & & & & \\
\hline
\textit{lit\_night\_13\_14} & Coef. & Std. Err. & \textit{z} & \textit{P>|z|} & \textit{[90\% Conf. Interval]} \\
\hline
ploy & -0.444 & 0.189 & -2.35 & 0.019 & -0.756 -0.133 \\
aadt\_1000 & 0.027 & 0.006 & 4.84 & 0.000 & 0.018 0.036 \\
surf\_3 & 0.254 & 0.107 & 2.38 & 0.017 & 0.078 0.429 \\
spd\_limit & 0.047 & 0.007 & 6.74 & 0.000 & 0.035 0.058 \\
num\_lanes & 0.206 & 0.076 & 2.71 & 0.007 & 0.081 0.331 \\
length & 0.192 & 0.030 & 6.31 & 0.000 & 0.142 0.242 \\
turn\_lane\_right & 0.728 & 0.170 & 4.29 & 0.000 & 0.449 1.007 \\
region3 & 0.453 & 0.152 & 2.98 & 0.003 & 0.203 0.704 \\
region4 & 0.430 & 0.140 & 3.08 & 0.002 & 0.200 0.659 \\
median\_concrete & -0.877 & 0.287 & -3.06 & 0.002 & -1.349 -0.406 \\
median\_guard & -0.868 & 0.476 & -1.82 & 0.068 & -1.652 -0.084 \\
median\_ditch & -0.656 & 0.172 & -3.82 & 0.000 & -0.939 -0.373 \\
_cons & -2.159 & 0.409 & -5.28 & 0.000 & -2.832 -1.486 \\
/lnalpha & -0.767 & 0.128 & & & -0.977 -0.556 \\
alpha & 0.465 & 0.059 & & & 0.376 0.573 \\
\hline
\text{Likelihood-ratio test of alpha=0:} & chibar2(01) = 423.57 & Prob>=chibar2 = 0.000 \\
\end{tabular}
\end{table}
Many conclusions may be drawn in regard to significant factors and the impact that they have on nighttime crashes. According to the results, the use of polyurea was significantly different from using waterborne paint or the other materials considered. Polyurea showed a reduction in crashes that was significant at the 95 percent confidence level with a z-value of -2.35. Modified urethane, tape, and STP showed insignificant results, which can be interpreted as a negligible difference between the applications of modified urethane, tape, STP, and waterborne paint in terms of influencing the frequency of nighttime crashes.

Other factors can be interpreted in a similar manner. AADT had a significant impact on the number of crashes. An increase in AADT is linked to an increase in nighttime crashes, which corresponds to the known fact that increased exposure increases the likelihood of collisions. In terms of length, a significantly positive z-value supports the fact that a longer length of roadway will experience more crashes simply due to exposure. Additionally, as speed limit increases, the chance of nighttime crashes is also increased. This is proven by a z-value of 6.74 for speed limit.

Several other environmental factors were found to have a significant impact. Roadways with composite pavement surfaces showed an increase in nighttime crashes compared to roadways with rigid or flexible pavement surfaces. Composite pavement material implementation was significant at 95 percent confidence with a z-value of 2.38. Locations with right turn lanes showed a significant increased number of nighttime crashes over locations with no turn lanes, left turn lanes, or both right and left turn lanes. The three types of medians that were significant, concrete barrier, guardrail, and graded with a ditch, all showed a significant reduction in crashes when compared to undivided roadways or roadways with a curb median with a significance of 90 percent or greater.

As previously mentioned two MDOT regions, Regions 5 and 6, were excluded from the selected data due to a lack of information from the guardrail inventory. Regions 2 and 7 were not significantly different from Region 1; therefore, they were removed from the model. Regions 3
and 4 showed a significant increase in nighttime crashes over Regions 1, 2 and 7. This may be due to variances in area types or population.

Using the previously described method, the statistical modeling results were assembled into a crash prediction expression. The coefficients and variables were compiled as follows:

\[
\text{Nighttime Crashes} = \exp \left( -2.159 - 0.444 \times \text{poly} + 0.027 \times \text{aadt} \_1000 + 0.254 \times \text{surf} \_3 + 0.047 \times \text{spd} \_\text{limit} + 0.206 \times \text{num} \_\text{lanes} + 0.192 \times \text{length} + 0.728 \times \text{turn} \_\text{lane} \_\text{right} + 0.453 \times \text{region} \_3 + 0.430 \times \text{region} \_4 - 0.877 \times \text{median} \_\text{typ} \_\text{concrete} - 0.868 \times \text{median} \_\text{typ} \_\text{guard} - 0.656 \times \text{median} \_\text{typ} \_\text{ditch} \right)
\]

With this equation, the crash modification and crash reduction factors can be calculated by isolating single variables. As previously discussed, polyurea had significantly different results than waterborne paint. The CMF for polyurea was derived from the above prediction expression and calculated to be:

\[
CMF_{\text{poly}} = \exp (-0.444) = 0.64
\]

From the CMF, the CRF can also be calculated:

\[
CRF_{\text{poly}} = 1 - CMF_{\text{poly}} = 0.36
\]

From the developed CMF, it is noted that the implementation of polyurea rather than waterborne could result in a reduction of nighttime crashes by 36 percent.
CHAPTER IV

SURVEY ON DELINEATION PRACTICES

Methodology

In order to identify delineation systems that have been implemented and the criteria used when deciding which systems to implement, a survey of other states was conducted. The goal was to discover what Michigan and other states consider as critical factors when deciding which delineation system is most applicable. The main goal was to receive responses from neighboring states of Michigan, i.e. Minnesota, Wisconsin, Illinois, Indiana, and Ohio, as well as states throughout the country and parts of Canada. From the literature review, delineation practices were identified for inquiry. The delineation systems selected for the survey included the following:

- Painted markings
- Recessed markings
- Durable markings (e.g. thermoplastic, MMA, epoxy, polyurea, etc.)
- Raised pavement markers (RPMs)
- Snowplowable RPMs (SRPMs)
- Post-mounted delineators (includes chevrons)
- Barrier delineators
- Guardrail delineators
- Rumble strips, centerline
- Rumble strips, shoulders

After answering which systems were implemented, participants identified criteria that was significant to the decision making process. The decision criteria were also established.
through literature review. The criteria included in the survey for each delineation system included the following:

- Pavement surface (asphalt or concrete)
- Pavement condition (remaining service life)
- Impact of weather/winter maintenance
- Service life
- Average cost
- Maximum AADT (traffic volume)
- Road geometry
- Location of line (centerline, edge line, etc.)
- Traffic composition
- Speed limit
- Durability
- Retroreflectivity

Each decision factor was given a level of significance, from very insignificant to very significant, or indicated as not considered. In addition, participants commented on the performance and disadvantages of each system as well as providing the minimum, average, and maximum lifespan and unit cost.

The entire survey was developed online using a survey developer (questionpro.com). After being finalized, the survey was distributed via email to contacts that had been established by a previous survey. The complete survey is included in the Appendix.
Results and Discussion

In order to identify where delineation systems are implemented and what criteria is used to decide on implementation, a survey was conducted. In all, 22 participants completed the survey. The following sections detail the results of the survey on delineation practices.

Survey Participants

In total, 20 states and 2 provinces contributed to the survey. Figure 12 shows the states and provinces that participated in the survey. The majority of the states that participated were within the Midwest. All states neighboring Michigan submitted responses, including Minnesota, Wisconsin, Illinois, Indiana, and Ohio.

![Participating states and provinces.](image)
**Delineator Systems**

The responses for the question regarding the implementation of delineation systems are summarized in Figure 13. As previously stated, durable markings include thermoplastic, MMA, epoxy, polyurea, etc. In terms of all participants, the delineation systems that were implemented by all participating states and provinces include post-mounted delineators as well as centerline and shoulder rumble strips. Other delineation systems that have been implemented include sprayable thermoplastic (non-durable thermoplastic application), tenth mile delineation, intersection corner delineation, and profiled pavement markings.

Various reasons were provided for not using specific delineation systems. For painted markings, one reason given for not implementing them was that the state only uses epoxy for all roadways. In terms of recessed markings, reasons for not using them include cost, lack of snow, and impact on pavement. For durable markings, states do not implement them due to the insufficient life span that does not offset the extra cost. For raised pavement markings (RPMs), states are not using them due to snow plowing. A few states have implemented snowplowable RPMs for this reason; however, a couple states do use them temporarily in work zones. In terms of snowplowable RPMs, reasons for not implementing them include lack of snow, durability, unit cost, maintenance, and safety concerns (castings going through windshields).
**Decision Criteria by System**

For each delineation system, participants were asked to rate a number of criteria on their significance. For all questions regarding decision criteria, the responses are shown as a weighted average where significance is given the following values: 0 (Not Considered), 1 (Very Insignificant), 2 (Insignificant), 3 (Neutral), 4 (Significant), and 5 (Very Significant). The results from these questions are summarized in the subsequent paragraphs.

**Painted Markings**

In Figure 14, the decision criteria is shown for painted markings. The most significant criteria for all responses was the average cost followed by durability. For Michigan, the most significant criteria was the pavement condition followed by impact of weather and average cost.
This response is similar to that of the neighboring states. Other decision factors include size of job, temperature, tracking concerns, and ease of maintenance.

In terms of performance and effectiveness of painted markings, the following were noted:

- Ease of maintenance with multiple crews
- Best value for the cost
- Reapplied every 1-2 years
- No longer used on high volume roadways due to lack of durability
- Better application practices yield better performance

The following are issues that have been faced with painted markings:

- Snowplowing/salt greatly reduce performance
- Not reflective when wet, poor reflectivity overall, and loss of retroreflectivity over time
- Poor performance on new pavement and roads with high AADT
- Have to be repainted annually
Often necessary to supplement with another form of delineation

**Recessed Markings**

In terms of recessed markings, Figure 15 depicts the decision criteria by significance. Overall, the most significant criteria were pavement condition followed by durability. Michigan and its neighboring states followed a similar trend with Michigan responding that pavement condition and durability as well as impact of weather as very significant decision criteria. Other decision factors include quantity as well as size and type of project.

Performance and effectiveness of recessed markings were evaluated as follows:

- Increase life of any marking material
- Effective in areas with snow removal
- Wet weather inhibits performance due to grooves filling with water

Issues that have been faced with recessed markings include:

- Depth of groove too deep
- Some materials do not perform well in the groove
• Equipment limits application
• Cost more than surface-applied markings
• Recessing limits wet-night visibility
• Recess must be clean before marking application

**Durable Markings**

Figure 16 shows the decision criteria by significance for durable markings, e.g. thermoplastic, MMA, epoxy, polyurea, etc. For all participants, the most significant criteria were pavement condition followed by durability. Michigan also responded that pavement condition and durability were very significant as well as retroreflectivity being significant. Other decision factors include quantity and project type.

![Figure 16 Decision criteria for durable markings.](image)

Performance and effectiveness for durable markings were noted as follows:

• Extended life span over other marking materials
• Good wet reflectivity but declines over life of the product
• Perform well when recessed
• Important for urban and high traffic areas

The following are issues that have been faced with durable markings:
• Snow removal greatly decreases performance
• White grays over time
• May be considerably more expensive than other alternatives
• Adhesion and retroreflectivity lost over the winter
• Early failure, especially late season installation
• Easily incorrectly installed

**Raised Pavement Markings**

In Figure 17, the decision criteria for raised pavement markings (RPMs) is shown. The most significant criteria for all participants were impact of weather and winter maintenance followed by maximum AADT. Michigan does not implement RPMs. One neighboring state indicated that they use RPMs; however, no criteria were marked as considered.

![How significant are the following criteria when selecting RPMs over other delineation systems in your jurisdiction?](chart)

*Figure 17 Decision criteria for raised pavement markings.*
In terms of performance and effectiveness of RPMs, the following were noted:

- Most effective wet-night performance
- Liked by the public
- Used in areas not snowplowed

The followed issues are associated with RPMs:

- Many get plowed off
- Periodic replacement is necessary
- Removed by passing traffic
- May be obscured by grit if placed in a groove

**Snowplowable Raised Pavement Markings**

Figure 18 shows the decision criteria for SRPMs. Overall, the most significant decision criteria were pavement condition, service life, maximum AADT, and durability. SRPMs are not implemented in Michigan; however, 60 percent of neighboring states implement them. Another decision factor noted was quantity.

![Figure 18 Decision criteria for snowplowable raised pavement markings.](image-url)
The performance and effectiveness were summarized as follows:

- Work well and are effective
- Have good wet-night performance
- Concern about steel casing that is generally used
- Liked by the public

Issues that have been faced with SRPMs include:

- Casing may be dislodged and become a projectile by a passing vehicle and might hit or puncture a windshield
- Reflectors may require frequent replacement
- Snow plows remove metal casing as asphalt ages

**Post-Mounted Delineators**

In Figure 19, the decision criteria for post-mounted delineators is depicted. The most significant criteria was road geometry for all responses; the same is true for states neighboring Michigan. This is also consistent with Michigan’s response of road geometry being the only criteria of significance. Other criteria include type of roadway, crash history, and summer maintenance (grass mowing).
Figure 19 Decision criteria for post-mounted delineators.

Figure 20 shows the distribution of the use of rigid or flexible post mounted delineators. Half of the participants indicated that their jurisdiction used both types. Also, Figure 21 shows the distribution of the decision criteria for rigid and flexible delineators. Of all the responses, 26 percent indicated that the same criteria is used for both rigid and flexible delineators while 37 percent responded that the criteria are different. For the states with varying criteria, differences include area (whether they are likely to be hit), road geometry, and width of shoulder.

In terms of performance and effectiveness of post-mounted delineators, the following were noted:

- Effective especially during poor visibility and weather
- May be quickly damaged

Issues that have been faced with post-mounted delineators include:

- Difficult to maintain due to mowing/snow removal and low priority repair
- Poor reflective sheeting
Figure 20 Use of rigid and flexible post-mounted delineators.

Figure 21 Decision criteria used for varying post types.

**Barrier Delineators**

Figure 22 shows the decision criteria by significance for barrier delineators. The most significant criteria for all responses were road geometry and service life. The only significant criteria for Michigan was road geometry, which was also one of the most significant criteria for neighboring states. Other criteria include crash history and roadway type.

**Figure 22 Decision criteria for barrier delineators.**
The evaluation of performance and effectiveness of barrier delineators is as follows:

- Especially useful on ramps and horizontal curves
- Provide nighttime delineation

Issues that have been faced with barrier delineators include:

- Keeping up with replacement of missing markers
- May be damaged/dislodged due to snow removal or vehicle collision
- Adhesive doesn’t last without proper surface prep
- Rarely replaced when damaged/dislodged
- Durability varies between providers

**Guardrail Delineators**

In Figure 23, the significance of decision criteria for guardrail delineators is shown. Overall, the most significant criteria was retroreflectivity. For neighboring states, the most significant criteria were durability and retroreflectivity. Michigan’s response differed with the only significant criteria being road geometry. Another factor that is consider is crash history.

In terms of effectiveness and performance of guardrail delineators, the following were noted:

- Effectiveness depends on installation height
- Provide nighttime/poor weather delineation

Issues that have been faced with guardrail delineators include:

- Keeping up with replacements
- Dirt on the reflective material – not self-cleaning with rain
- Not replaced when damaged/removed
- Damaged by snow removal
Centerline Rumble Strips

Figure 24 depicts the decision criteria for centerline rumble strips by significance.

Overall, the most significant criteria was road geometry, which was also significant for Michigan and its neighboring states. For Michigan, the speed limit was another significant criterion that was also the most significant for neighboring states. Other criteria include crash history, area type, and lane/shoulder widths.
The performance and effectiveness of centerline rumble strips were as follows:

- Work well and are effective
- Important safety feature
- Increase wet-night retroreflectivity to markings placed over them
- Reduce crashes – especially roadway departure

Issues associated with centerline rumble strips include:

- Pavement deterioration – introduce moisture at pavement joints
- Noise complaints from residents
- Accommodating bicyclists and horse drawn carriages
- Maintenance of rumble strips and markings

**Shoulder Rumble Strips**

In Figure 25, the decision criteria for shoulder rumble strips is shown. The most significant criteria overall was pavement condition which was considered insignificant by Michigan. Road geometry and speed limit were considered most significant for Michigan and two
of the most significant criteria for neighboring states and all participants. Other criteria include crash history, lane/shoulder width, and area type.

The performance and effectiveness of shoulder rumble strips are summarized as follows:

- Important safety feature
- Effective at keeping motorists in their lanes
- Reduce crashes

Issues that have been faced with shoulder rumble strips include the following:

- Pavement deterioration
- Opposition from other agencies/contractors when initially proposing
- Noise complaints from residents
- Accommodating bicyclists
Pavement Marking Materials

Figure 26 depicts pavement marking materials by the amount that they are implemented. Of all marking materials implemented, the following indicate the level of implementation: 0 (None, 0%), 1 (Very Little, <15%), 2 (Little, 15-40%), 3 (Some, 40-60%), 4 (A Lot, >60%). These values were used to calculate the weighted average of implementation. The most commonly implemented marking material for all participants was waterborne (low temperature).

In Michigan, polyurea and overlay cold plastic tape are most implemented. For all other participants, polyurea is not commonly implemented, having an average level of implementation less than 1. Overlay cold plastic tape was third highest for neighboring states in terms of level of implementation. Additionally, latex paint is commonly used by other states. Epoxy is one of the most implemented materials for neighboring states. However, neither epoxy nor latex paint are implemented in Michigan.

Other pavement marking materials that have been implemented include preformed thermoplastic, inlaid cold plastic, standard waterborne (not low temperature), hi-build paint, and low VOC acetone.

![Figure 26 Pavement marking materials by level of implementation.](image-url)
**Life Span**

For each delineation systems, participants were asked to provide the minimum, average, and maximum unit cost. Figure 27 shows the average life span of the delineation systems considered from all participants. The average minimum, average, and maximum were calculated. In general, painted markings have the shortest life span while rumble strips have the longest life span.

![Average Life Span](image)

*Figure 27 Average delineator life span in years.*

**Unit Cost**

Additionally, the unit cost was requested for each delineation system. In Figure 28, the average unit cost for each delineation system as given by all participants is depicted. Delineation systems that are measured in US dollars per linear foot are shown on the left while the other delineators that are measured in US dollars each is shown on the right. The least expensive delineators are painted markings while the most expensive are SRPMs.
Critical Factors

It was identified that there were decision criteria for each delineation system that could be deemed critical. In order to quantify critical decision factors, criteria with an average significance rating of 4 or 5, i.e. significant or very significant, respectively, were determined to be critical. Additionally, factors with an average significance between 3 and 4 were considered important.

Critical and important factors are summarized using these criteria in Tables 3 and 4. Critical factors are indicated with a “C” while important factors are denoted with an “I”. Cells left blank indicate an average significance that was less than three. In addition, Table 3 summarizes the average significance as rated by neighboring states while the average significance as indicated by non-neighboring states and provinces is included in Table 4.

In general, neighboring states seem to consider service life, average cost, durability, and retroreflectivity as the most significant factors concerning painted, recessed, and durable markings. In addition, the implementation of centerline and shoulder rumble strips is dependent on the speed limit in neighboring states. For non-neighboring states, durable markings are often implemented after considering several criteria including remaining service life of the pavement, impact of winter maintenance, maximum AADT, durability, and reflectivity. Also for non-
neighboring states, the implementation of centerline and shoulder rumble strips is dependent upon the pavement surface material and remaining service life. Other conclusions can be made in a similar fashion.

Table 3 Critical factors as indicated by neighboring states

<table>
<thead>
<tr>
<th>Delineation System</th>
<th>Decision Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pavement Surface (asphalt or concrete)</td>
<td>Pavement Condition (remaining service life)</td>
</tr>
<tr>
<td>Painted markings</td>
<td>I</td>
</tr>
<tr>
<td>Recessed markings</td>
<td>I</td>
</tr>
<tr>
<td>Durable markings (e.g. thermoplastic, MMA, epoxy, polyurea, etc.)</td>
<td>I</td>
</tr>
<tr>
<td>Raised pavement markers (RPMs)</td>
<td></td>
</tr>
<tr>
<td>Snowplowable RPMs (SRPMs)</td>
<td>I</td>
</tr>
<tr>
<td>Post-mounted delineators (includes chevrons)</td>
<td>I</td>
</tr>
<tr>
<td>Barrier delineators</td>
<td>I</td>
</tr>
<tr>
<td>Guardrail delineators</td>
<td>I</td>
</tr>
<tr>
<td>Rumble strips, centerline</td>
<td>I</td>
</tr>
<tr>
<td>Rumble strips, shoulders</td>
<td>I</td>
</tr>
</tbody>
</table>
### Table 4 Critical factors as indicated by non-neighboring states

<table>
<thead>
<tr>
<th>Delineation System</th>
<th>Decision Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pavement Surface (asphalt or concrete)</td>
</tr>
<tr>
<td>Painted markings</td>
<td>I</td>
</tr>
<tr>
<td>Recessed markings</td>
<td>I</td>
</tr>
<tr>
<td>Durable markings (e.g. thermoplastic, MMA, epoxy, polyurea, etc.)</td>
<td>I</td>
</tr>
<tr>
<td>Raised pavement markers (RPMs)</td>
<td>I</td>
</tr>
<tr>
<td>Snowplowable RPMs (SRPMs)</td>
<td>I</td>
</tr>
<tr>
<td>Post-mounted delineators (includes chevrons)</td>
<td></td>
</tr>
<tr>
<td>Barrier delineators</td>
<td>I</td>
</tr>
<tr>
<td>Guardrail delineators</td>
<td>I</td>
</tr>
<tr>
<td>Rumble strips, centerline</td>
<td>I</td>
</tr>
<tr>
<td>Rumble strips, shoulders</td>
<td>I</td>
</tr>
</tbody>
</table>
CHAPTER V

COST-BENEFIT ANALYSIS

Methodology

All transportation systems possess negative factors as well as advantageous characteristics. Cost-benefit analysis is a tangible way to evaluate the impact of certain delineation systems. This method is beneficial because it goes beyond statistical modeling. Results from the modeling were applied in order to discover the actual advantage or disadvantage when accounting for all aspects of implementation.

First, the costs and benefits associated with delineation were identified. Then, the factors are applied to select sites. However, many of these factors are not quantifiable. As discussed in the literature review, the main benefits of delineation include aiding traffic flow, increasing driver comfort, and increasing traffic safety. Since these factors are not easily measured, the most quantifiable feature is crash reduction. The CMF developed from the statistical analysis was applied to the selected sites and combined with the length in order to predict the reduction in crashes per mile.

In terms of costs, delineation systems possess initial installation costs as well as maintenance costs. However, this analysis only considered the initial cost to determine the benefit at the time of implementation. Lifespan and unit cost data from the survey on delineation practices was implemented for this portion of the analysis.

In order to perform cost-benefit analysis, the associated costs and benefits must be tabulated. Calculated or previously developed CMFs were used to calculate CRFs to calculate the potential reduction in crashes that could result from the implementation of an alternative delineation system. The annual reduction in crashes due to the implementation of an alternative
delineation system with a reduction in crashes represented by $CRF_i$ was calculated by the following:

\[
Reduction \text{ in Crashes per Mile} = CRF_i \times Average \text{ Annual Crashes per mile}
\]

To quantify the reduction in crashes, the cost per crash must be applied. A value of $19,999 was developed to be the average crash cost by considering monetary costs, including medical care and emergency responses as well as non-monetary costs such as quality-of-life when considering crashes occurring in Michigan. Annual crash saving due to a reduction in crashes was computed using the following equation:

\[
Average \text{ Annual Savings per Mile} = (Reduction \text{ in Crashes per Mile} \times Average \text{ Crash Cost})
\]

In addition to benefits, the costs were also calculated. Since installation costs were the main consideration with delineation systems, the only costs calculated were installation costs per mile. When considering alternative marking materials, the cost was the differential installation cost, which was the difference in installation costs for the alternative material per mile and the current material cost per mile in order to assess the added costs due to using one material in place of another. When considering the addition of systems where they were formerly absent, e.g. SRPMs, the cost included the entire installation cost.

In order to be able to compare costs and benefits that are observed over a number of years, it was necessary to calculate the present value of the benefits and the costs. The present value shows the benefits and costs at any given time, thus allowing for comparison. For the costs, the present value was taken to be the installation fee in cases where a system was added or differential cost if it was being improved. The present value of benefits was calculated using the following:
\[ PV_{\text{benefits}} = (Average\ Annual\ Savings\ per\ Mile) * \left( \frac{(1 + R)^N - 1}{R + (1 + R)^N} \right) \]

where \( PV_{\text{benefits}} \) is the present value of savings, \( R \) is the predetermined discount rate, and \( N \) is the service life in years. The discount rate is dependent on the life span (Circular A-94 Appendix C, 2016).

The final step in cost-benefit analysis is to develop the benefit-cost ratio (BCR) using the following equation:

\[ BCR = \frac{PV_{\text{benefits}}}{PV_{\text{costs}}} \]

A BCR greater than one means that the benefits of an alternative system outweigh the costs, proving the potential to be beneficial upon implementation (Kwigizile, et. al., 2015).

**Results and Discussion**

Based on the results of the statistical modeling for pavement marking materials, it was found that the implementation of polyurea might reduce the number of nighttime crashes when compared to waterborne paint. It was therefore deemed necessary to perform cost-benefit analysis in order to accommodate for all variables that would be encountered to see the overall effect of implementing polyurea on a wider scale. Additionally, it was noted from the survey that the majority of states that neighbor Michigan use SRPMs while Michigan does not use them. Consequently, cost-benefit analysis was done using previously developed CMFs on selected sites to determine if SRPMs should be further considered for implementation in Michigan. The cost-benefit results for these alternative delineation systems are detailed in the following sections.
**Alternative Pavement Marking Material Implementation**

Waterborne paint, while widely implemented in Michigan, may not be the ideal marking material. Michigan indicated in the survey on delineation practices that waterborne paint has limited durability and a significant reduction in performance after winter maintenance. Therefore, it may be beneficial to explore the implementation of durable markings on a wider scale.

As discussed previously, polyurea was found to be the only material that performed significantly different from waterborne paint. In a hypothetical scenario, polyurea was applied to all selected sites that currently have waterborne paint implemented. The number of sites included in this analysis numbered 123. Polyurea possesses an average total unit cost of $0.85 per linear foot for installation, which was indicated by Michigan’s response to the survey. Additionally, Michigan indicated that polyurea has an average service life of five years. The installation cost of waterborne paint was indicated to be $0.15 per linear foot. A discount rate of 2.4 percent was applied for the five-year life span as well as the calculated CRF of 0.36 for nighttime crashes when polyurea was implemented rather than waterborne paint (Circular A-94 Appendix C, 2016). The results of the cost-benefit analysis for polyurea implementation are shown in Table 5.

As shown in the results, the implementation of polyurea may have a positive effect. The impact of widely implementing polyurea had an average BCR of 19.63. These results might point toward increased consideration of other durable markings due to the potential safety benefit that outweighs the cost. This difference in safety performance may be due to a difference in material properties including durability and retroreflectivity.
Table 5 Summary of cost-benefit analysis for polyurea implementation

<table>
<thead>
<tr>
<th>Crash Reduction for Polyurea Implementation</th>
<th>Costs and Benefits of Polyurea Implementation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Nighttime Crashes Per Mile (2013-2014)</td>
<td>Average Annual Savings per Mile</td>
</tr>
<tr>
<td>Average Annual Nighttime Crashes per Mile</td>
<td>Average Annual Crash Reduction per Mile</td>
</tr>
<tr>
<td>Average Annual Crash Reduction per Mile</td>
<td>Present Value Benefits per Mile</td>
</tr>
<tr>
<td>Average Annual Savings per Mile</td>
<td>Polyurea Installation Cost per Mile</td>
</tr>
<tr>
<td>Waterborne Installation Cost per Mile</td>
<td>Differential Installation Cost per Mile</td>
</tr>
<tr>
<td>Benefit to Cost Ratio (BCR) per Mile</td>
<td></td>
</tr>
</tbody>
</table>

| 4.325 | 2.162 | 0.778 | $15,569 | $72,540 | $4,488 | $792 | $3,696 | 19.63 |

The results obtained from the cost-benefit analysis are limited to the average annual nighttime crashes per mile for the selected sites. However, these results may be applied to specific roadways with a known number of nighttime crashes per mile. By applying the calculated CRF for the implementation of polyurea rather than waterborne paint, the BCR for theoretical conditions may be calculated. These results are shown in Figure 29. The BCR increases as the number of nighttime crashes per mile increases. Additionally, a line is included for when the BCR is equal to one, i.e. when the costs and benefits are equal. Any calculated BCR that is greater than one is considered to represent a significant benefit.

Figure 29 Benefit-cost ratio by average annual nighttime crashes per mile.
**SRPM Implementation**

SRPMs are not currently implemented in Michigan. As stated in the literature review, SRPMs were found to increase nighttime crashes on roadways with four lanes that had an AADT less than 20,000. However, there was found to be a potential reduction in nighttime crashes on four-lane roadways with higher AADTs. Due to unknown factors such as curvature, it was assumed that SRPMs would be installed every 80 feet resulting in 66 SRPMs implemented per mile. In terms of installation costs, the average cost was calculated from the survey responses to be $37.89 for each SRPM unit. Additionally, the average lifespan of 5.5 years was acquired from survey responses resulting in an applied discount rate of 2.475 percent (Bahar, et. al., 2004; Circular A-94 Appendix C, 2016).

For this cost-benefit analysis, the sites considered were limited to the 286 sites that were used for statistical modeling. Within these selected sites, 10 segments were identified as having four lanes with an AADT between 20,000 and 60,000; a CRF of 0.06 was applied to this selection. In addition, six sites were identified to possess four lanes and an AADT greater than 60,000; to these segments, a CRF of 0.33 was applied. It should be noted that the sample size was restricted to the selected sites due to the availability of known factors. The results of this analysis should be confirmed on a larger scale.

**Table 6 Summary of cost-benefit analysis of SRPM implementation**

<table>
<thead>
<tr>
<th>Number of Sites</th>
<th>AADT</th>
<th>CRF</th>
<th>Nighttime Crashes per Mile (2013-2014)</th>
<th>Average Annual Nighttime Crashes per Mile</th>
<th>Average Annual Nighttime Crash Reduction per Mile</th>
<th>Average Annual Savings per Mile</th>
<th>Present Value Benefits per Mile</th>
<th>SRPM Installation Costs per Mile</th>
<th>Benefit to Cost Ratio (BCR) per Mile</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>20,001-60,000</td>
<td>0.06</td>
<td>10.42</td>
<td>5.212</td>
<td>0.313</td>
<td>$6,254</td>
<td>$31,792</td>
<td>$2,501</td>
<td>12.71</td>
</tr>
<tr>
<td>6</td>
<td>&gt;60,000</td>
<td>0.33</td>
<td>18.93</td>
<td>9.465</td>
<td>3.123</td>
<td>$62,466</td>
<td>$317,551</td>
<td>$2,501</td>
<td>126.98</td>
</tr>
</tbody>
</table>
The results of the cost-benefit analysis for SRPM implementation are shown in Table 6. These results show that even with added costs of installation, SRPMs might have a significant impact on reducing nighttime crashes. On four-lane roadways with AADTs between 20,000 and 60,000, an average BCR was calculated to be 12.71. The greatest impact was seen on four-lane roadways with an AADT greater than 60,000. The BCR on these segments was 126.98, which shows a very positive impact for the investment. However, due to the small sample size of segments meeting the requirements, a definitive recommendation to implement SRPMs cannot be made. Further analysis with a larger sample size should be considered. Nevertheless, these results do justify continued research and the consideration of implementing SRPMs in the state of Michigan for roadways with a high AADT.
CHAPTER VI

CONCLUSION AND RECOMMENDATIONS

Conclusion

Safety benefit analysis was completed in order to assess delineation systems that are implemented in Michigan. Through literature review, several delineation practices, selection criteria, and previously developed crash modification factors were researched. Additionally, alternative systems that are implemented in other jurisdictions were also investigated through literature review.

Through data-driven analysis, the impact on the number of nighttime crashes was analyzed for alternative pavement marking materials used in the state of Michigan. Statistical modeling using a negative binomial regression was completed in order to determine if one material had any safety benefit over the others. Sites were selected, and pavement marking material inventory data were combined with crash data. It was found that the implementation of polyurea rather than waterborne paint could result in a significant reduction in observed nighttime crashes. Based on the modeling results, a CMF of 0.64 and a CRF of 0.36 were calculated for the implementation of polyurea rather than waterborne paint.

A survey on delineation practices was completed and resulted in the participation of 20 states in the U.S. and two provinces in Canada. Critical factors were identified for a variety of delineation systems. Additionally, unit cost and service life data were collected to be used in the cost-benefit analysis.

Through cost-benefit analysis, it was found that wider implementation of polyurea rather than waterborne paint may be beneficial as shown through a reduction in nighttime crashes. Analysis was performed to identify the cost savings if polyurea were to be implemented wherever there was waterborne paint. Additionally, SRPMs, which are not currently implemented in...
Michigan, were analyzed to identify the impact they would have if they were implemented in
Michigan based on previous research and developed crash modification factors. Based on the
results, further consideration should be given to the implementation of SRPMs.

**Recommendations**

As with other analysis completed with count data, a bias may occur due to a small sample
size. In order to remove any potential bias, it would be beneficial to obtain a larger sample size.
This may involve adding more years of crash data or more sites with known implemented
marking materials to increase the sample size.

Similarly, having a proportional amount from each MDOT region would aid in the
accuracy of the model. Conditions and attributes vary greatly between regions. Two regions were
not included in this research due to a lack of guardrail inventory information. Additionally,
including lighting information would be beneficial; however, a complete lighting inventory was
not available for this analysis. From the literature review, it was found that lighting has the
potential to reduce crashes. Being able to evaluate the impact it would have could lead to
advantageous cost-benefit analysis.

In the case of both guardrail and lighting inventories, a lack of information is the largest
hurdle. Additionally, acquiring such data is not an easy task. However, current systems may aid
in procuring this data. For example, some of the locations may be investigated by satellite
imaging.

For this analysis, the crash data was limited to nighttime crashes. Increasing the number
of years of crash data may allow for analysis of different crash types. Since delineation is
intended to define the safe operating area of the roadway and guide road users in the safest way
possible, it would be beneficial to be able to analyze lane departure crashes. This analysis would
have the most impact since one of the goals of delineation is to reduce the likelihood of such an
incident. Analyzing lane departures was not possible during this analysis due to a small sample of lane departure crashes within the two years of crash data used in the analysis.

The cost-benefit analysis indicated that the implementation of polyurea in place of waterborne paint as well as SRPMs on roadways with certain AADTs could have benefits that outweigh the associated increased costs. However, these conclusions were made based on small sample sizes that were restricted by inventory data. In order to further prove these results and support the implementation of these systems, it would be beneficial to increase the sample size for the cost-benefit analysis. Additionally, this analysis was limited to only initial installation costs even though other costs exist over the life cycle of the surface of implementation. To obtain comprehensive cost-benefit results, it would be necessary to perform cost-benefit analysis over the whole life cycle of the element being affected, which in this case is the pavement surface. Life cycle analysis would support the cost-benefit analysis performed for the delineation elements in this research.
REFERENCES


Whittaker, A. *The Safety Benefit of Continuous Narrow Painted Median Strips*. University of Southern Queensland, Faculty of Engineering & Surveying, 2012.
APPENDIX

Survey on Delineation Practices
Evaluating Road Delineation Practices in Michigan

Hello! You are invited to participate in a survey for a Michigan Department of Transportation (MDOT) research project, Evaluation of Road Delineation Practices in Michigan. Western Michigan University and Opus International Consultants Inc., in conjunction with MDOT, are performing a study in order to evaluate the current road delineation practices in Michigan as well as propose new alternative forms of delineation. In order to propose the most effective delineation practices, the research team is looking to other states in order to obtain the current delineation practices and the associated effectiveness. This is an in-depth survey to identify these practices in a comprehensive manner. Your responses will be strictly confidential and be used only for the present research project. If you have questions at any time about the survey or research, you may contact Dr. Valerian Kwizizile at (269) 276-3211 or by email at valerian.kwigizile@wmich.edu. Thank you very much for your time and support. Please start the survey by clicking on the CONTINUE button below.

1. What state are you from? If not in the U.S., please select "other" and specify. (will have a dropdown list of all states and "other" selection, if not in the US).

2. Which delineator systems are implemented in your state/jurisdiction? Check all that apply. **Multiple answers may be selected. The remainder of the survey depends on the delineators that are checked in this question.

- Painted markings
- Recessed markings
- Durable markings (e.g. thermoplastic, MMA, epoxy, polyurea, etc.)
- Raised pavement markers (RPMs)
- Snowplowable RPMs
- Post-mounted delineators (includes chevrons)
- Barrier delineators
- Guardrail delineators
- Rumble strips, centerline
- Rumble strips, shoulders
- Other (please specify) __________

**Parts a-i of Question 3 are only shown for the delineation systems not checked in Question 2.

3. (a) Why are you not using Painted Markings?

3. (b) Why are you not using Recessed Markings?

3. (c) Why are you not using Durable Markings?

3. (d) Why are you not using Raised Pavement Markings?

3. (e) Why are you not using Snowplowable Raised Pavement Markings?

3. (f) Why are you not using Post-Mounted Delineators?

3. (g) Why are you not using Barrier Delineators?

3. (h) Why are you not using Guardrail Delineators?

3. (i) Why are you not using Centerline Rumble Strips?

3. (j) Why are you not using Shoulder Rumble Strips?

**Question 4 is only shown if “Painted Markings” was checked in Question 2.

Painted Markings

70
4. (a) How significant are the following criteria when selecting PAINTED MARKINGS over other delineation systems in your jurisdiction? Indicate significance; indicate "Not Considered" if the criteria is not considered.

<table>
<thead>
<tr>
<th>Selection Criteria</th>
<th>Very Significant</th>
<th>Insignificant</th>
<th>Neutral</th>
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<th>Very Significant</th>
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<td>Pavement Condition (remaining service life)</td>
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<td>Impact of Weather/Winter Maintenance</td>
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<td>Service Life</td>
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<td>Maximum AADT (traffic volume)</td>
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</table>

4. (b) Please specify any other criteria not listed above:

4. (c) If there is documentation available for the PAINTED MARKING selection criteria indicated, are you able to share those documents that detail the guidelines with us? If "yes" is selected, we will contact you to retrieve that documentation.

- Yes
- No

4. (d) For PAINTED MARKINGS that have been implemented, please specify the range of service life and unit price. Please provide the minimum, average, and maximum service life and unit price in the spaces provided. For the unit price, please specify both the unit price (in US dollars) and the unit used (i.e. $100 per linear foot or other measurement) in the blank.

<table>
<thead>
<tr>
<th>Service Life (years)</th>
<th>Minimum</th>
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<tr>
<td>Unit Price (US dollars per &quot;unit&quot;)</td>
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</tbody>
</table>

4. (e) Please comment on the performance and effectiveness of PAINTED MARKINGS that are implemented in your jurisdiction:

4. (f) What issues have been faced with PAINTED MARKINGS that have been implemented in your jurisdiction?
Recessed Markings

5. (a) How significant are the following criteria when selecting RECESSED MARKINGS over other delineation systems in your jurisdiction? Indicate significance; indicate "Not Considered" if the criteria is not considered.

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<tr>
<th>Selection Criteria</th>
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5. (b) Please specify any other criteria not listed above:

5. (c) If there is documentation available for the RECESSED MARKING selection criteria indicated, are you able to share those documents that detail the guidelines with us? If "yes" is selected, we will contact you to retrieve that documentation.

- Yes
- No

5. (d) For RECESSED MARKINGS that have been implemented, please specify the range of service life and unit price. Please provide the minimum, average, and maximum service life and unit price in the spaces provided. For the unit price, please specify both the unit price (in US dollars) and the unit used (i.e. $100 per linear foot or other measurement) in the blank.

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<td>Unit Price (US dollars per &quot;unit&quot;)</td>
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</table>

5. (e) Please comment on the performance and effectiveness of RECESSED MARKINGS that are implemented in your jurisdiction:

5. (f) What issues have been faced with RECESSED MARKINGS that have been implemented in your jurisdiction?
**Question 6 is only shown if “Durable markings” was checked in Question 2.**

**Durable Markings (e.g. thermoplastic, MMA, epoxy, polyurea, etc.)**

6. (a) How significant are the following criteria when selecting DURABLE MARKINGS over other delineation systems in your jurisdiction? Indicate significance; indicate "Not Considered" if the criteria is not considered.

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<thead>
<tr>
<th>Selection Criteria</th>
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<td>Maximum AADT (traffic volume)</td>
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<td>Retroreflectivity</td>
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6. (b) Please specify any other criteria not listed above:

6. (c) If there is documentation available for the DURABLE MARKING selection criteria indicated, are you able to share those documents that detail the guidelines with us? If "yes" is selected, we will contact you to retrieve that documentation.

- Yes
- No

6. (d) For DURABLE MARKINGS that have been implemented, please specify the range of service life and unit price. Please provide the minimum, average, and maximum service life and unit price in the spaces provided. For the unit price, please specify both the unit price (in US dollars) and the unit used (i.e. $100 per linear foot or other measurement) in the blank.

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<tr>
<th></th>
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<th>Average</th>
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<tbody>
<tr>
<td>Service Life (years)</td>
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<tr>
<td>Unit Price (US dollars per &quot;unit&quot;)</td>
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</tbody>
</table>

6. (e) Please comment on the performance and effectiveness of DURABLE MARKINGS that are implemented in your jurisdiction:

6. (f) What issues have been faced with DURABLE MARKINGS that have been implemented in your jurisdiction?
**Question 7 is only shown if “Painted Markings,” “Recessed Markings,” or “Durable Markings” were checked in Question 2.**

### Pavement Marking Materials

7. (a) Of the marking materials used, how much of the following PAVEMENT MARKING MATERIALS are implemented in your jurisdiction? Indicate the amount as a percent of all materials implemented.

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<thead>
<tr>
<th>Material</th>
<th>None (0%)</th>
<th>Very Little (&lt;15%)</th>
<th>Little (15-40%)</th>
<th>Some (40-60%)</th>
<th>A Lot (&gt;60%)</th>
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</thead>
<tbody>
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<td>Regular-Dry</td>
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<tr>
<td>Waterborne (Low Temperature)</td>
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<tr>
<td>Sprayable Thermoplastic</td>
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<tr>
<td>Liquid Hot Applied Thermoplastic</td>
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<tr>
<td>Polyurea</td>
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<tr>
<td>Overlay Cold Plastic Tape</td>
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<tr>
<td>Overlay Cold Plastic Tape-Wet Reflective</td>
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<tr>
<td>Conventional Solvent Paint</td>
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<tr>
<td>Epoxy</td>
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<tr>
<td>Methyl Methacrylate (MMA)</td>
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<tr>
<td>Polyester</td>
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<td>Latex Paint</td>
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<tr>
<td>Marking Powder</td>
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<tr>
<td>Modified Urethane</td>
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<tr>
<td>Wet Reflective Beads/Elements</td>
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<tr>
<td>Contrast Markings</td>
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</table>

7. (b) Specify any other materials not listed that are implemented in your jurisdiction:

7. (c) Do you have a Qualified Products List and/or a material evaluation process? If "yes" is selected, we will contact you to retrieve that documentation.

- Yes
- No

**Question 8 is only shown if “Raised Pavement Markings” was selected in Question 2.**

### Raised Pavement Markings

8. (a) How significant are the following criteria when selecting RAISED PAVEMENT MARKINGS over other delineation systems in your jurisdiction? Indicate significance; indicate "Not Considered" if the criteria is not considered.

<table>
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<tr>
<td>Pavement Condition (remaining service life)</td>
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<tr>
<td>Impact of Weather/Winter Maintenance</td>
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<td>Service Life</td>
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<td>Maximum AADT (traffic volume)</td>
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<tr>
<td>Road Geometry</td>
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<td>Location of Line (centerline, edge line, etc.)</td>
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<td>Traffic Composition</td>
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</tbody>
</table>
8. (b) Please specify any other criteria not listed above:

8. (c) If there is documentation available for the RAISED PAVEMENT MARKING selection criteria indicated, are you able to share those documents that detail the guidelines with us? If “yes” is selected, we will contact you to retrieve that documentation.

- Yes
- No

8. (d) For RAISED PAVEMENT MARKINGS that have been implemented, please specify the range of service life and unit price. Please provide the minimum, average, and maximum service life and unit price in the spaces provided. For the unit price, please specify both the unit price (in US dollars) and the unit used (i.e. $100 per linear foot or other measurement) in the blank.

<table>
<thead>
<tr>
<th>Selection Criteria</th>
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<th>Insignificant</th>
<th>Neutral</th>
<th>Significant</th>
<th>Very Significant</th>
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<tbody>
<tr>
<td>Pavement Surface (asphalt or concrete)</td>
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<tr>
<td>Pavement Condition (remaining service life)</td>
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</table>

8. (e) Please comment on the performance and effectiveness of RAISED PAVEMENT MARKINGS that are implemented in your jurisdiction:

8. (f) What issues have been faced with RAISED PAVEMENT MARKINGS that have been implemented in your jurisdiction?

**Question 9 is only shown if “Snowplowable Raised Pavement Markings” was selected in Question 2. Snowplowable Raised Pavement Markings

9. (a) How significant are the following criteria when selecting SNOWPLOWS RAISED PAVEMENT MARKINGS over other delineation systems in your jurisdiction? Indicate significance; indicate “Not Considered” if the criteria is not considered.
9. (c) If there is documentation available for the SNOWPLOWABLE RAISED PAVEMENT MARKING selection criteria indicated, are you able to share those documents that detail the guidelines with us? If "yes" is selected, we will contact you to retrieve that documentation.
   - Yes
   - No

9. (d) For SNOWPLOWABLE RAISED PAVEMENT MARKINGS that have been implemented, please specify the range of service life and unit price. Please provide the minimum, average, and maximum service life and unit price in the spaces provided. For the unit price, please specify both the unit price (in US dollars) and the unit used (i.e. $100 per linear foot or other measurement) in the blank.

<table>
<thead>
<tr>
<th>Minimum</th>
<th>Average</th>
<th>Maximum</th>
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</thead>
<tbody>
<tr>
<td>Service Life (years)</td>
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<tr>
<td>Unit Price (US dollars per &quot;unit&quot;)</td>
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</table>

9. (e) Please comment on the performance and effectiveness of SNOWPLOWABLE RAISED PAVEMENT MARKINGS that are implemented in your jurisdiction:

9. (f) What issues have been faced with SNOWPLOWABLE RAISED PAVEMENT MARKINGS that have been implemented in your jurisdiction?

**Question 10 is only shown if "Post-Mounted Delineators" was selected in Question 2.

Post-Mounted Delineators
10. (a) How significant are the following criteria when selecting POST-MOUNTED DELINEATORS over other delineation systems in your jurisdiction? Indicate significance; indicate "Not Considered" if the criteria is not considered.

<table>
<thead>
<tr>
<th>Selection Criteria</th>
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<th>Insignificant</th>
<th>Neutral</th>
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<td>Pavement Surface (asphalt or concrete)</td>
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<td>Pavement Condition (remaining service life)</td>
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<td>Maximum AADT (traffic volume)</td>
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<td>Location of Line (centerline, edge line, etc.)</td>
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<td>Traffic Composition</td>
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<td>Retroreflectivity</td>
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</tbody>
</table>

10. (b) Please specify any other criteria not listed above:

10. (c) Do you use rigid or flexible post-mounted delineators?
   1. Rigid
   2. Flexible
3. Both Rigid and Flexible

10. (d) Are the selection criteria the same for rigid and flexible delineators?
   - Yes
   - No (Please use the box below to specify differences in criteria.)

10. (e) If there is documentation (e.g. manufacturer, Qualified Products List, detailed selection process, etc.) available for the POST-MOUNTED DELINEATOR selection criteria indicated, are you able to share those documents that detail the guidelines with us? If “yes” is selected, we will contact you to retrieve that documentation.
   - Yes
   - No

10. (f) For POST-MOUNTED DELINEATORS that have been implemented, please specify the range of service life and unit price. Please provide the minimum, average, and maximum service life and unit price in the spaces provided. For the unit price, please specify both the unit price (in US dollars) and the unit used (i.e. $100 per linear foot or other measurement) in the blank.

<table>
<thead>
<tr>
<th>Service Life (years)</th>
<th>Minimum</th>
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<tbody>
<tr>
<td>Unit Price (US dollars per &quot;unit&quot;)</td>
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</table>

10. (g) Please comment on the performance and effectiveness of POST-MOUNTED DELINEATORS that are implemented in your jurisdiction:

10. (h) What issues have been faced with POST-MOUNTED DELINEATORS that have been implemented in your jurisdiction?

**Question 11 is only shown if “Barrier Delineators” was checked in Question 2.

Barrier Delineators

11. (a) How significant are the following criteria when selecting BARRIER DELINEATORS over other delineation systems in your jurisdiction? Indicate significance; indicate "Not Considered" if the criteria is not considered.

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<thead>
<tr>
<th>Selection Criteria</th>
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<th>Neutral</th>
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<tr>
<td>Pavement Condition (remaining service life)</td>
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<td>Impact of Weather/Winter Maintenance</td>
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<td>Service Life</td>
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<td>Maximum AADT (traffic volume)</td>
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<td>Location of Line (centerline, edge line, etc.)</td>
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<td>Traffic Composition</td>
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</tbody>
</table>
11. (b) Please specify any other criteria not listed above:

11. (c) If there is documentation (e.g. manufacturer, Qualified Products List, detailed selection process, etc.) available for the BARRIER DELINEATOR selection criteria indicated, are you able to share those documents that detail the guidelines with us? If "yes" is selected, we will contact you to retrieve that documentation.
   - Yes
   - No

11. (d) For BARRIER DELINEATORS that have been implemented, please specify the range of service life and unit price. Please provide the minimum, average, and maximum service life and unit price in the spaces provided. For the unit price, please specify both the unit price (in US dollars) and the unit used (i.e. $100 per linear foot or other measurement) in the blank.

<table>
<thead>
<tr>
<th>Service Life (years)</th>
<th>Minimum</th>
<th>Average</th>
<th>Maximum</th>
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</thead>
<tbody>
<tr>
<td>Unit Price (US dollars per &quot;unit&quot;)</td>
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</tbody>
</table>

11. (e) Please comment on the performance and effectiveness of BARRIER DELINEATORS that are implemented in your jurisdiction:

11. (f) What issues have been faced with BARRIER DELINEATORS that have been implemented in your jurisdiction?

**Question 12 is only shown if “Guardrail Delineators” was checked in Question 2.**

Guardrail Delineators

12. (a) How significant are the following criteria when selecting GUARDRAIL DELINEATORS over other delineation systems in your jurisdiction? Indicate significance; indicate "Not Considered" if the criteria is not considered.

<table>
<thead>
<tr>
<th>Selection Criteria</th>
<th>Very Significant</th>
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<th>Neutral</th>
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<td>Impact of Weather/Winter Maintenance</td>
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<td>Maximum AADT (traffic volume)</td>
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</table>
12. (b) Please specify any other criteria not listed above:

12. (c) If there is documentation (e.g. manufacturer, Qualified Products List, detailed selection process, etc.) available for the GUARDRAIL DELINEATOR selection criteria indicated, are you able to share those documents that detail the guidelines with us? If "yes" is selected, we will contact you to retrieve that documentation.
- Yes
- No

12. (d) For GUARDRAIL DELINEATORS that have been implemented, please specify the range of service life and unit price. Please provide the minimum, average, and maximum service life and unit price in the spaces provided. For the unit price, please specify both the unit price (in US dollars) and the unit used (i.e. $100 per linear foot or other measurement) in the blank.

<table>
<thead>
<tr>
<th>Selection Criteria</th>
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<th>Maximum</th>
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</thead>
<tbody>
<tr>
<td>Service Life (years)</td>
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<tr>
<td>Unit Price (US dollars per &quot;unit&quot;)</td>
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</table>

12. (e) Please comment on the performance and effectiveness of GUARDRAIL DELINEATORS that are implemented in your jurisdiction:

12. (f) What issues have been faced with GUARDRAIL DELINEATORS that have been implemented in your jurisdiction?

**Question 13 is only shown if “Rumble Strips, centerline” was checked in Question 2.**

**Rumble Strips**

13. (a) How significant are the following criteria when selecting CENTERLINE RUMBLE STRIPS over other delineation systems in your jurisdiction? Indicate significance; indicate "Not Considered" if the criteria is not considered.

<table>
<thead>
<tr>
<th>Selection Criteria</th>
<th>Very Insignificant</th>
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<td>Impact of Weather/Winter Maintenance</td>
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<td>Service Life</td>
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<td>Maximum AADT (traffic volume)</td>
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<tr>
<td>Retroreflectivity</td>
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</table>

13. (b) Please specify any other criteria not listed above:

13. (c) If there is documentation available for the CENTERLINE RUMBLE STRIP selection criteria indicated, are you able to share those documents that detail the guidelines with us? If "yes" is selected, we will contact you to retrieve that documentation.
13. (d) For CENTERLINE RUMBLE STRIPS that have been implemented, please specify the range of service life and unit price. Please provide the minimum, average, and maximum service life and unit price in the spaces provided. For the unit price, please specify both the unit price (in US dollars) and the unit used (i.e. $100 per linear foot or other measurement) in the blank.

<table>
<thead>
<tr>
<th>Service Life (years)</th>
<th>Minimum</th>
<th>Average</th>
<th>Maximum</th>
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</thead>
<tbody>
<tr>
<td>Unit Price (US dollars per &quot;unit&quot;)</td>
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</table>

13. (e) Please comment on the performance and effectiveness of CENTERLINE RUMBLE STRIPS that are implemented in your jurisdiction:

13. (f) What issues have been faced with CENTERLINE RUMBLE STRIPS that have been implemented in your jurisdiction?

**Question 14 is only shown if “Rumble Strips, shoulder” was checked in Question 2.

**Shoulder Rumble Strips**

14. (a) How significant are the following criteria when selecting SHOULDER RUMBLE STRIPS over other delineation systems in your jurisdiction? Indicate significance; indicate "Not Considered" if the criteria is not considered.

<table>
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<tr>
<th>Selection Criteria</th>
<th>Very Insignificant</th>
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<td>Pavement Condition (remaining service life)</td>
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<td>Maximum AADT (traffic volume)</td>
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<td>Location of Line (centerline, edge line, etc.)</td>
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</table>

14. (b) Please specify any other criteria not listed above:
14. (c) If there is documentation available for the SHOULDER RUMBLE STRIP selection criteria indicated, are you able to share those documents that detail the guidelines with us? If "yes" is selected, we will contact you to retrieve that documentation.

- Yes
- No

14. (d) For SHOULDER RUMBLE STRIPS that have been implemented, please specify the range of
service life and unit price. Please provide the minimum, average, and maximum service life and unit price in the spaces provided. For the unit price, please specify both the unit price (in US dollars) and the unit used (i.e. $100 per linear foot or other measurement) in the blank.

<table>
<thead>
<tr>
<th></th>
<th>Minimum</th>
<th>Average</th>
<th>Maximum</th>
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<tr>
<td>Service Life (years)</td>
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<tr>
<td>Unit Price (US dollars per &quot;unit&quot;)</td>
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</table>

14. (e) Please comment on the performance and effectiveness of SHOULDER RUMBLE STRIPS that are implemented in your jurisdiction:

14. (f) What issues have been faced with SHOULDER RUMBLE STRIPS that have been implemented in your jurisdiction?

15. (a) If you do snow plowing, what type of plow blades are used? Select all that apply. If you do not do snow plowing, select "N/A."
   1. N/A
   2. Front mounted
   3. Under body
   4. Side/wing blades
   5. Other (Please specify) __________

15. (b) If you do ice control, what products do you use? Select all that apply. If you do not do ice control, select "N/A."
   1. N/A
   2. Salt
   3. Sand
   4. Other de-icing product (Please specify) __________

Please provide your contact information so that we can contact you about any documentation you indicated you are able to share.
16. (a) First Name
16. (b) Last Name
16. (c) Phone
16. (d) Email Address

Thank you for participating in our survey!