*Sponsoring Organization:*
*Michigan Department of Transportation*

# Evaluating Road Delineation Practices in Michigan

## Final Report

**Andrew Ceifetz, Joyce Yassin, Patrick Andridge**
Opus International Consultants Inc.

**Valerian Kwigizile, Jun-Seok Oh, Brenda Burdick**
Western Michigan University

Date: March 31, 2017
Reference: RC 1646
Status: Final Report

## Technical Report Document

| 1. Report No. RC 1646 | 2. Government Accession No. N/A | 3. MDOT Project Manager Mary Bramble |
|---|---|---|
| 4. Title and Subtitle Evaluating Road Delineation Practices in Michigan | | 5. Report Date March 31, 2017 |
| | | 6. Performing Organization Code H-U1022.00 |
| 7. Author(s) Andrew Ceifetz, Joyce Yassin, Patrick Andridge, Valerian Kwigizile, Jun-Seok Oh, Brenda Burdick | | 8. Performing Org. Report No. N/A |
| 9. Performing Organization Name and Address Opus International Consultants Inc. Detroit Office 27333 Meadowbrook Road, Suite 210 Novi, MI 48377 | | 10. Work Unit No. (TRAIS) N/A |
| | | 11. Contract No. 2016-0019 |
| | | 11(a). Authorization No. |
| 12. Sponsoring Agency Name and Address Michigan Department of Transportation Research Administration 8885 Ricks Rd. P.O. Box 30049 Lansing MI 48909 | | 13. Type of Report & Period Covered |
| | | 14. Sponsoring Agency Code N/A |
| 15. Supplementary Notes | | |

**16. Abstract**

This research was conducted to assist the Michigan Department of Transportation in assessing the State's current delineation program. Opus International Consultants (Opus) and Western Michigan University (WMU) were retained to undertake this review and analysis, including a review of existing literature and current state-of-the-art, a delineation survey with follow-up of state and Canadian provinces, and finally a benefit-cost and alternatives analysis to consider potential changes to MDOT's existing program. In the Michigan context, statistical analysis shows potential benefits for wider adaptation of polyurea pavement markings, snowplowable raised pavement markers on high-AADT roadways, and freeway lighting at interchanges.

| 17. Key Words | 18. Distribution Statement |
|---|---|
| delineation, short range, long range, pavement markings, benefit-cost, safety | No restrictions. This document is available to the public through the Michigan Department of Transportation. |

| 19. Security Classification - report | 20. Security Classification - page | 21. No. of Pages | 22. Price |
|---|---|---|---|
| Unclassified | Unclassified | 90 | N/A |

# Disclaimer

This publication is disseminated in the interest of information exchange. The Michigan Department of Transportation (hereinafter referred to as MDOT) expressly disclaims any liability, of any kind, or for any reason, that might otherwise arise out of any use of this publication or the information or data provided in the publication. MDOT further disclaims any responsibility for typographical errors or accuracy of the information provided or contained within this information. MDOT makes no warranties or representations whatsoever regarding the quality, content, completeness, suitability, adequacy, sequence, accuracy or timeliness of the information and data provided, or that the contents represent standards, specifications, or regulations.

# Acknowledgements

The research team would like to thank Ms. Mary Bramble, the project manager, and Mr. Michael Townley, the research manager, for their support on this project. Also, we would like to thank the following members of the Research Advisory Panel for their suggestions and comments, which helped in shaping and carrying out this study:

Mark Bott, MDOT

Adam Vandercook, MDOT

Chuck Bergmann, MDOT

Kim Ault, MDOT

Erin Chelotti, MDOT

Jackie Pethers, MDOT

Bob Conway, FHWA

Julie Johnston, FHWA

# Contents

# List of Tables

# List of Figures

# Executive Summary

The Michigan Department of Transportation (MDOT) issued a request for proposal (RFP) for a research project to assess the State's current delineation program. As stated in the RFP, "MDOT spends millions of dollars a year installing and maintaining pavement markings, rumble strips and delineators as part of its delineation program".

The Department sought an objective review of its current delineation practices to identify opportunities for improvement, including consideration of different delineation materials and methods. The ultimate goal was the development of a "…cost efficient asset-managed delineation system on MDOT roadways that provides positive guidance to keep motorists safely in their lane during normal driving conditions and strives to deliver delineation in severe weather conditions".

Opus International Consultants (Opus) and Western Michigan University (WMU) were retained to undertake this review and analysis, including a review of existing literature and current state-of-the-art, a delineation survey with follow-up of state and Canadian provinces, and finally a benefit-cost and alternatives analysis to consider potential changes to MDOT's existing program.

The results of the literature review provided an initial comparison of MDOT's current delineation program to those practices employed in other states and existing research evaluating the operational and safety effectiveness, retroreflectivity, and remaining service life of various methods and materials. Findings of the state-of-the-art review include the following key points:

- Delineation programs should include both long and short range delineation to supplement each other and other guidance as appropriate.
- Both durable and non-durable pavement marking materials have been shown to be cost effective in different situations and the use of these markings should be based on several factors, including but not limited to cost, pavement condition/remaining service live, and AADT.
- Other key influencing factors that should be considered when identifying a delineation system include geometry, pavement surface, lighting, climate, winter maintenance, speed, traffic conditions, roadway functional classification, and human factors.
- Proven physical delineation materials and practices that improve safety include rumble strips, lighting, alignment signs, and delineators/reflective posts.
- Physical and painted delineation measures may be supplemented by other practices which enhance their visibility, including maintenance of clear zones and sight triangle, reviewing and updating sign placement, and other maintenance activities to keep reflective surfaces clear and unobstructed.

The finished literature review, in conjunction with further guidance from the Research Advisory Panel (RAP) helped focus the development of the nationwide survey. Twenty states, including all states surrounding Michigan, and two Canadian provinces responded to the survey, providing detailed

information regarding the materials and methods employed in their delineation programs, as well as feedback regarding their experience with each. This information generally included use rates, typical service life and cost estimates, among other details. A variety of delineation systems are available, however post-mounted delineators, centerline rumble stripes, and shoulder rumble strips are the only ones implemented by all participating states and provinces. The critical factors for neighboring states were found to include service life, average cost, durability, and retroreflectivity as the most significant in regard to painted, recessed, and durable markings.

This information was then combined with a number of other sources, including the results of the literature review, guidance and additional information from MDOT, as well as crash modification factors from the Crash Modification Factors Clearinghouse and those developed by the research team for this project. In the Michigan context, statistical analysis shows potential benefits for wider adaptation of polyurea pavement markings, snowplowable raised pavement markers on high-AADT roadways, and freeway lighting at interchanges. 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.

A review of lighting at freeway interchanges is recommended because locations where lighting is not present and experience more than one nighttime crash every two years may benefit from a significant crash reduction if lighting is added. Consideration should also be given to including snowplowable raised pavement markings on 4-lane roadways with greater than 20,000 AADT and especially on those segments of roadway having greater than 60,000 AADT; this implementation would provide positive benefits based on the benefit-cost ratios calculated. Durable pavement markings have been shown to provide a greater return on investment at locations with higher AADT while lower durability materials perform sufficiently on lower volume roads. Pavement condition and remaining service life at a location is also another factor to consider when selecting an appropriate marking material. On roadways averaging as few as one nighttime crash per mile, using polyurea pavement markings rather than waterborne may have significant benefits (e.g. BCR greater than one). The break-even costs for the marking material implementation were calculated to determine the cost per linear foot when the BCR was set equal to one as demonstrated in the duplicated figure below. Any cost lower than the break-even cost will result in benefit with a BCR greater than one.

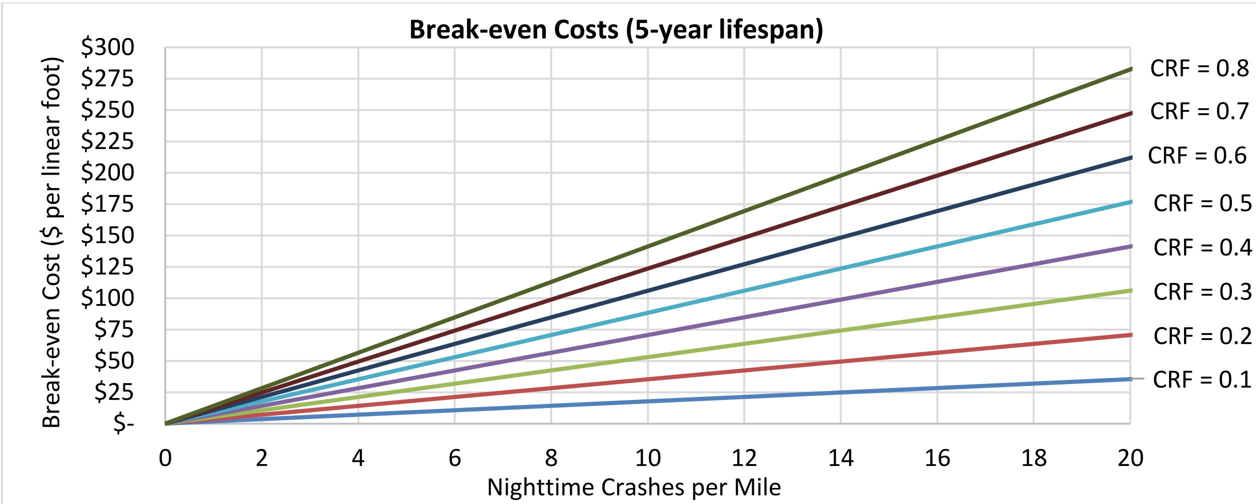



**Figure 52 (duplicate): Break-even costs for marking materials with varying CRFs**

Recommendations also included improving the inventory of delineation features, a standard replacement cycle for delineators, and considerations for MDOT's pavement marking selection guidelines. MDOT should investigate updating their pavement marking selection guidelines to include additional factors including AADT and the service life of the markings when choosing between waterborne or more durable markings. To improve the durability of post mounted delineators, it is recommended to continue the use of reflective sign sheeting and consider replacing reflective buttons on regularly scheduled sign replacement programs. Improving the inventory delineation features should also be considered to better understand the potential benefits of changes to MDOT's delineation program and aid in managing an important safety asset.

In discussing the use of post-mounted delineators with MDOT's Engineering Operations Committee, a suggestion was made to swap an occasional white delineator with a green one. As post-mounted delineators augment the delineation systems mandated in the MUTCD, this would not be in conflict. In snowy conditions, the green reflectors would provide contrast with the white background created by blowing snow, and would help provide greater awareness than just white reflectors. Green was suggested as it complements the green LEDs currently being installed on MDOT's snowplows to help motorists identify these vehicles as distinct from other construction or emergency vehicles on a roadway.

# 1 Introduction

## 1.1 Background

### 1.1.1 Objectives

MDOT spends millions of dollars a year installing and maintaining pavement markings, rumble strips and delineators as part of its delineation program. Installation of pavement markings, rumble strips, and delineators is completed via construction contract with a variety of materials. Pavement marking maintenance is completed via an annual restriping program using two products; waterborne paint (WB) and sprayable thermoplastic (STP). These two products are considered to be '1 year' products. Sprayable thermoplastic is used based on traffic volumes due to its quick dry time and reduced tracking/paint claims. The majority of pavement markings on MDOT's trunkline system currently are waterborne and sprayable thermoplastic, though other materials have been used at different times and in specific locations.

Keeping in line with the Department's roadway delineation goal:

*"Deliver a cost efficient asset-managed delineation system on MDOT roadways that provides positive guidance to keep motorists safely in their lane during normal driving conditions and strives to deliver delineation in severe weather conditions."*

This research was undertaken to determine if the current delineation program is appropriate or if a new process should be instituted.

### 1.1.2 Scope

Tasks included a literature review, survey of other states, review of Michigan data, and an alternative strategy analysis. The best practices of neighboring states with the same snow plow conditions assisted in identifying different styles of delineators and durable pavement markings. Ultimately, the cost/benefit relationship of different materials, lifecycles, and applications were used to recommend an effective alternative that accounts for safety benefits, longevity, ease of installation and maintenance, and associated costs.

## 1.2 Experimental Design

An in-depth literature review was conducted to provide a state-of-the-art delineation practices baseline. This was paired with a survey of other states to determine similarities and differences in the practices of states with similar environmental conditions. Information derived from the literature review and survey of other states was used to help guide an analysis of MDOT practices to develop benefit-cost analyses for a series of delineation methods and materials to help identify potential improvements in Michigan's delineation program.

The survey was conducted via QuestionPro.com, and allowed participants to submit their answers electronically. Participants were asked both subjective as well as quantitative questions regarding their state's use of various delineation treatments. The survey results are presented in Section 3.3 and the text of the survey is included as an appendix at the end of this report.

Field reviews were conducted of various types of pavement marking treatments in Michigan, Wisconsin, and Ohio to compare how different markings are used in other states.

Additionally, various reflectors that are being trialed in Michigan were reviewed noting some of the benefits and drawbacks related to each type.

Statistical analysis was conducted of various delineation treatments in context with Michigan's roadways, available crash data, and costs, to identify beneficial treatments for the system. The crash modification factors were obtained from published literature when estimating the effects of treatments not currently used in Michigan, and developed from representative roadways within the State for estimating the expanded application of treatments used around Michigan.

# 2 Literature Review

Per the Federal Highway Administration (FHWA), delineation refers to any method of defining the roadway operating area for the driver. The Manual on Uniform Traffic Control Devices (MUTCD) lists minimum requirements for delineating roadways. To fully understand the state of knowledge concerning roadway delineation components and influential design factors, a literature review was conducted. The literature review details findings about roadway delineation systems including both short and long distance viewing delineation for all portions of the roadway except intersections. Short range delineation includes longitudinal lines, other pavement markings, and rumble strips. Long range delineation includes mainline lighting, reflective delineators, and reflective sign posts for horizontal alignment signs. Critical design factors were also detailed such as geometry, lighting, and climate to determine the most influential components.

## 2.1 Review of Previous Research

*The Roadway Delineation Practices Handbook (1)* was developed to aid practitioners in selecting roadway delineation systems and how to maintain such systems. It states that roadway delineation is a crucial factor in improving traffic flow, driving comfort, and traffic safety. It defines delineation as one device, or a combination of control devices, which regulate, warn, or provide tracking information and guidance to the driver. While warning signs are also considered part of the delineation system, guide signs are not. Examples of delineation materials include:

- Painted markings,
- thermoplastic and other durable markings,
- raised pavement markers, and
- post-mounted delineators.

Retroreflectivity is very essential for a delineation system to be effective at night. Retroleflectivity can be provided through the use of:

- *glass beads*: can be dropped on, premixed in marking material, or a combination of the two.
- *wet reflective optics*: can be added to a bead mixture and dropped onto premixed material.
- *prismatic cube-corner retroreflection:* commonly used in raised pavement markers (RPMs) and buttons. Prismatic sheeting is also used for retroreflective panels for post-mounted delineators.

Delineators used must be visible in daylight and darkness, as well as in periods of adverse weather such as rain and fog. Persons with reduced or impaired vision and color vision deficiencies (such as older drivers) have greater visibility needs that can be provided by delineators. Criteria for visibility of delineators include:

- *luminance*: the total amount of light the driver receives from a marking
- *contrast*: the ratio of luminance from the marking to luminance from its surroundings

- *conspicuity*: the likelihood that a driver will notice a certain target at a given distance
- *legibility*: the probability that a driver will understand the message that delineation is meant to convey

Parameters that limit delineation visibility include:

- *physical parameters*: created by limits of the driver's sensory perception

*psychophysical parameters*: result from driver's own limited ability to assimilate and understand the available stimuli that his senses are capable of perceiving.

The important variables that should be considered in determining the most appropriate delineation treatment and technique include:

- roadway geometry,
- weather and climate,
- traffic volume and composition, and
- type of substrate material (asphaltic concrete (AC) or Portland cement concrete (PCC)).

Roadway delineation systems include both short and long distance viewing for all portions of the roadway (except intersections for this research). As stated in the *FHWA Roadway Delineation Practices Handbook (1)*, "The primary purpose of a roadway delineation system is to provide the visual information needed by the driver to steer a vehicle safely in a variety of situations." In addition to short range and long range delineations systems, other delineation innovations such as colored shoulder pavement, wider pavement markings, painted medians, and gateway treatments were researched.

Opus Central Laboratories researched visual performance of a mixed system of delineation comprised of pavement markings, raised reflective pavement markers, edge marker posts, chevrons and other reflective sheeting, tactile markings and signs. Collectively these devices provide long range delineation needed for route guidance, and short range delineation needed for vehicle placement within the travel lane *(2)*.

### 2.1.1 Short Range Delineation

Short range delineation, such as longitudinal pavement markings, are required for safe and efficient driver operations. Part 3 of the MUTCD defines markings as an important function to guide and inform road users. The material used for markings should provide the specified color throughout their useful life, and consideration should be given to selecting pavement marking materials that will minimize tripping or loss of traction for road users *(3)*. Pavement marking materials can be divided into two common types: nondurable and durable. Nondurable materials are primarily paints, and durable materials consist of epoxy, thermoplastics, polyurea, polyurethane, and tapes. Each material has specific characteristics, including service life expectancy, color quality, retro-reflectivity, special application methods, and cost *(4)*.

Other types of short range delineation include but are not limited to raised pavement markings and rumble strips. Details of each type of short range delineation are summarized below.

#### 2.1.1.1 Pavement Marking Types

The different types of pavement marking materials were assessed to gather a better understanding of the different methods, service life expectancy, and retro-reflectivity, among other factors.

*i. Painted markings*

Painted markings can be either longitudinal or transverse used to show positive guidance such as lanelines, centerlines, edgelines, crosswalks, and stop bars. They also show areas where drivers are not permitted to travel (negative guidance), such as gore areas, islands, and painted medians. The MUTCD provides details and specifics. The three important interactive elements of the paint system include:

- the paint itself (pigment and binder);
- beads (retroreflective glass spheres); and,
- pavement surface (substrate).

Alternative ways to classify paint include:

- inclusion of wet reflective optics;
- manner of application (cold-applied or hot-applied); and,
- drying time (conventional (7+ min), fast dry (2-7 min), quick dry (0.5-2 min), and instant dry (<0.5 min)).

The three main components of paint are:

- *binder (base material)*: oil (alkyd resin), oleoresin (modified alkyd, drying oil [dispersion] varnish), rubber base (chlorinated rubber), and water;
- *pigment (for color and retroreflectivity)*; and,
- *solvent*.

Causes of pavement marking failures include several mechanisms:

- loss of substance by abrasive wear on the upper surface;
- cohesive failure of the paint (within the paint layer);
- adhesive failure at the interface with the pavement substrate;
- lack of surface preparation; and/or,
- time of placement (temperatures and nighttime dew can cause failure).

Waterborne paint is generally considered the oldest and most widely-used pavement marking material. Currently it is rarely used for special markings, and durability is highly sensitive to the roadway surface and traffic volumes.

*ii. Thermoplastic materials*

There are two types of thermoplastic materials: sprayable thermoplastic and extruded thermoplastic. Extruded thermoplastic materials are less frequently used due to the poor bonding and formation in high snowfall areas and on concrete pavements. Sprayable thermoplastics are used more often due to thinner coatings, better bonding, and better distribution. Thermoplastic materials are used as an alternative to paint markings due to:

- readiness for immediate use;
- superior durability; and,
- potential for long-term economy and traffic safety.

The break-even point ranges from three to six years for the material to be cost effective. The exact chemical composition varies considerably, however the formulation of thermoplastic pavement markings includes three basic components:

- plastic and plasticizer (binder);
- pigment and fillers; and,
- glass beads.

Thermoplastic materials are classified by the type of binder used:

- Alkyd-based - use synthetic alkyd resins for a binder; or,
- Hydrocarbon-based - use petroleum-based organic compounds as a binder.

Thermoplastic markings have been used in the U.S. since the 1950's; they are solid at room temperature but liquefy when heated to facilitate application. Thermoplastics are also sensitive to the roadway surface and traffic volumes, and care must be taken during the application process to ensure controlled application.

*iii. Preformed Tapes*

Cold-applied plastic pavement marking tapes are supplied in continuous rolls of various lengths and widths. Preformed tapes are most frequently used for special markings such as crosswalks, stop bars, legends and symbols. Cold-applied preformed tapes are reported to perform better on bituminous asphalt surfaces than on Portland cement concrete *(1)*. Therefore, MDOT suggests recessing preformed installations on concrete.

The application of preformed wet reflective tapes provide more reflectivity than non-wet reflective tapes and are used for longitudinal lines. Due to material cost, MDOT recommends that wet reflective tape only be used for freeway broken and dotted lane lines, and when installed on new concrete requires the addition of black preformed shadow tape.

Preformed tapes generally do not require expensive application equipment or experienced operators to place. There is no required drying or curing time, but preformed tape application is generally a manual process so slower rates of production are expected as compared to paints or thermoplastic materials for longitudinal lines.

*iv. Other Marking Materials*

In addition to the conventional paints, thermoplastic, and preformed tapes the following pavement markings were identified:

- Latex paint
- Epoxy paint
- Polyester, solids
- Epoxy thermoplastic
- Methyl Methacrylate
- Marking powder
- Polyurea
- Modified urethane
- Preformed thermoplastic
- Multipolymer

Latex paint, also known as water-based paint, is the most widely used marking material. These materials are similar to conventional paints in theory of operation, but the hazardous materials have been removed.

Epoxy paint was first introduced in the 1970's and showed durability on both HMA and concrete pavements. While requiring longer drying times of up to 40 minutes – though newer formulations may cure in as few as 30 seconds – epoxies may be applied in lower ambient temperatures than thermoplastics.

Polyester markings have limited use nationwide. It is recommended for asphalt roads that have medium-to high volume traffic.

Epoxy thermoplastic is composed of epoxy resins, pigment, filler, and glass beads. This material differs from most epoxies because no hardener is used. This type of marking is not widely used due to a poor cost service life ratio.

Methyl Methacrylate (MMA) creates a very strong bond to pavements and may be sprayed or extruded. Recent trials have shown that with proper application, MMA markings are extremely durable even when exposed to snowplows and deicers.

Marking powder is easy to handle and apply but requires special installation equipment. The powder is combusted as it is deposited on the pavement and the high heat of the application cause the material to bond to the substrate. This material is considered as a durable traffic paint.

Polyurea markings are considered durable on both HMA and concrete pavements. Having a short drying time (approximately two minutes), they may be applied at ambient temperatures down to freezing.

Modified urethane is a two-component, durable marking material, with similar performance characteristics to those of polyurea and epoxy.

Performed thermoplastic is applied to the pavement cold with adhesive material. It is most frequently used for crosswalks, stop bars, words, symbols, and other specialized treatments.

Multipolymer can be applied on concrete and asphalt with no primer, however primer is recommended for longevity purposes. Durability of this marking is directly related to the applied mil thickness.

#### 2.1.1.2 Assessing Pavement Markings

There have been several attempts to quantify the service life of various marking technologies under different traffic and plowing conditions in various states including Indiana, Minnesota, Colorado, and Oregon; Canadian provinces including Quebec and Alberta; as well as other countries such as Australia and Japan. Similar to Michigan, Indiana uses waterborne paints for longitudinal pavement markings, which are repainted at least annually. A synthesis study was conducted by researchers at Purdue University to determine the state-of-practice of pavement marking materials. Different types of pavement marking materials were investigated. Specifically, materials were judged on their durability and retroreflectivity as well as cost and service life. Findings include widespread use of waterborne paints across the nation due to its inexpensive application, although this material is not suitable for roadways that experience high traffic volumes and winter maintenance activities due to quick loss of retro-reflectivity and a short service life of about one year *(5)*.

The primary types of materials used for marking in the U.S. include:

- Waterborne paints
    - low VOC
    - least expensive
    - glass beads added to increase retroreflectivity
    - shortest service life
    - not suitable for high volume roads
- Conventional solvent paints
    - glass beads added to increase retroreflectivity
    - over VOC limit
- Thermoplastic
    - low VOC
    - moderate cost and durability
    - best on asphalt (mixed reviews for concrete)
- Tape
    - high initial cost
    - 4-6 times the reflectivity of waterborne paints

- may lose reflectivity quickly
- inlaid or recessed lasts longer than surface applied

- Epoxy
  - two component paint
  - highly durable on asphalt or concrete
  - low VOC
- Methyl methacrylate
  - two component material with low VOC
  - may outperform thermoplastics in durability, cost, visibility, and service life, especially in cold/snowy climate, but can be difficult to place in production
- Polyester
  - best on asphalt
  - low VOC but involves hazardous chemicals
- Polyurea
  - two component process
  - may be applied in low temp
  - not affected by humidity
  - works on asphalt or concrete

Retroreflectivity may determine the end of a service life and is impacted by the size of the glass beads and the method/accuracy of application (mixed in or applied while wet). More durable materials should be selected for high AADT roadways to reduce worker exposure to traffic and increase the service life.

Important factors to consider:

- Marking Material
- Pavement Type – concrete/asphalt
- Highway Type – two-lane or multi-lane
- Traffic Conditions – volume/composition
- Weather Conditions

A study conducted in Minnesota indicates that for low volume roads (AADT of 10,000 or less) paint may be the most cost-effective material, and for roadways with higher volumes (AADT of 10,000 or more) a more durable product, such as epoxy or tape, may be more cost-effective and reduce worker exposure to traffic *(6)*. Similarly, a research study was conducted in Colorado to determine the cost-effectiveness of epoxy-based pavement marking material. The study consisted of four pilot projects that implemented enhanced marking materials which were warrantied. Overall, the enhanced specifications for pavement marking material performed slightly better than the control projects, but cost more. Therefore the implementation of the enhanced specifications was not a cost-effective tool for Colorado *(7)*.

In Oregon they evaluated the use of recessed durable pavement markings implemented in snowy areas. Various inlaid durable pavement marking materials and slot designs were evaluated. Pavement materials consisted of the following types: Dura-Stripe (methyl methacrylate), Permaline (thermoplastic), and 3M

Tape. Glass beads were also applied to all the materials except the tape. The materials were tested for two winter seasons. The results showed that Permaline did not perform well on concrete pavement, instead it was recommended to use Dura-Stripe markings on concrete pavements because it performed better. The 3M Tape was only tested on asphalt pavement and performed well based on durability and retro-reflectivity performance *(8)*.

The study, *Service Life of Durable Pavement Markings (9)*, evaluated the service life (visibility and durability performance) of 11 different types of pavement markings in 19 states over a four year period. The primary factors considered in the study were pavement marking material (epoxy, thermoplastic, etc.), color of line (white or yellow), and type of roadway (freeway, non-freeway ≤40 mph, non-freeway ≥45 mph). The service life results were broken out into two categories: 1) locations at which no reflective raised pavement markers (RRPMs) or roadway lighting are present, or 2) locations with pavement markings installed in the presence of RRPMs or roadway lighting. A sample of the service life results for white pavement markings on freeways in locations with no lighting are provided in Table 1.

**Table 1: White Pavement Marking Service Life**

| **Pavement Marking Material** | **Average Service Life in:** | |
|---|---|---|
| | **Million vehicles** | **Elapsed Months** |
| Thermoplastic | 7.5 | 22.6 |
| Polyester | 9.6 | 20.8 |
| Profiled Tape | 6.3 | 19.6 |
| Profiled Thermoplastic | 6.5 | 18.4 |
| Profiled Poly (Methyl Methacrylate) | 7.9 | 14.0 |
| Epoxy | 2.4 | 12.8 |
| Poly (Methyl Methacrylate) | 3.7 | 11.9 |
| Waterborne Paint | 3.7 | 10.4 |

A 2002 NCHRP Synthesis documents the current and best practices for long-term pavement markings. Out of sixteen types of longitudinal marking materials in use, waterborne paint is the most commonly used by transportation agencies followed by thermoplastic. Thermoplastic is more costly than waterborne paint whereby waterborne paint expenditures are 17% of the pavement marking budgets and is striped on almost 60% of state highway mileages and thermoplastic expenditures are 35% of the budgets and is striped on almost 23% of state highway mileages *(10)*.

Studies outside of the United States have also been performed to assess pavement marking materials. In Canada, the province of Quebec investigated pavement marking retro-reflectivity in cold regions by conducting a literature review and worldwide survey. The results of the study found that durable pavement marking materials, such as thermoplastics, can be good alternatives to traditional waterborne paints. More durable markings such as methyl methacrylate (MMA) were found to not be cost-effective. Several solutions were mentioned to extend durability and retro-reflectivity, such as: recessed pavement markings to protect from snowplow wear, apply markings on rumble strips (e.g. rumble stripes), and the use of snowplowable reflective (or raised) pavement markers (SRPM) *(11)*. Methods of pavement marking were investigated by the Alberta government. Conventional paints begin to fade once subjected to traffic and may also be below required retroreflectivity levels. Therefore, alternative durable marking materials were researched and reported. The recommended practices is to consider installing durable pavement markings on four-lane divided highways where AADT exceeds 15,000, on rural two-lane undivided highways where the AADT exceeds 5,000, and on urban two-lane undivided highways where the AADT exceeds 8,000. Durable pavement markings are described as follows: premium traffic paint, durable plastic markings, traffic marking tape, and snowplowable raised pavement markers. Recessing any of the materials increases the service life due to protection from snowplows, and compared to conventional waterborne paint, durable pavement markings have been shown to reduce collision costs by 2.5% *(12)*.

In other countries, such as Japan, pavement markings are also damaged by snowplows. A system was proposed to apply recessed pavement markings that incorporate rumble strips. It was found that waterborne paints are not durable enough to be used as recessed pavement markings, therefore STP was suggested instead. It was also recommended to use highly reflective beads to improve nighttime visibility under rainy conditions *(13)*. And in Australia, waterborne paint is generally used in rural areas and durable pavement material is used in the metropolitan area and on roads that experience heavy traffic volumes.

The majority of pavement markings are also required to use glass beads to provide adequate retro-reflectivity *(14)*. Retro-reflectivity of pavement markings is an important factor to provide visibility, particularly during adverse weather and nighttime conditions. In Minnesota, the provision is to recess all wet reflective/recoverable materials to insure continued wet weather performance after snow plowing operations *(15)*. Examples of recessing techniques include grooving, inlaying, installing in a sinusoidal rumble strip, etc. Wet recoverable materials include larger glass beads, profiled markings and rumble stripes, which enhance performance of pavement markings during wet weather conditions but still lose retroreflective properties when covered with water. Wet reflective materials enhance performance of pavement marking during wet weather conditions and retain their retroreflective properties when covered by water. In one study, wet-reflective pavement markings were evaluated in three states: Minnesota, North Carolina, and Wisconsin. The wet-reflective markings were upgraded from the standard marking materials to wet-reflective markings applied as paint, tape, or thermoplastic material. The results suggested that wet reflective materials can be cost effective, particularly on multilane roads. Crash reduction factors for wet-road crashes were found to be 24.9% on multilane roads and 13.9% on freeways *(16)*.

In addition to weather and maintenance activities, there are other factors that impact retro-reflectivity of pavement markings. A research study took place in South Carolina to investigate several factors that would have significant impact on retro-reflectivity degradation. Their findings determined that the most significant factors include pavement surface type, marking material, marking color, and maintenance activities. Maintenance activities such as snowplowing and remarking influenced retro-reflectivity values significantly. Using the findings in the study, statistical models of degradation rates where successfully developed. One model shows that that the linear model for epoxy on concrete had a steeper downward trend than the models for thermoplastic on asphalt. In other words, the thermoplastic on asphalt provided more lasting retro-reflectivity when compared to epoxy on concrete *(17)*. A study conducted by the Illinois Center of Transportation evaluated pavement markings on Portland cement concrete (PCC) and hot-mix asphalt (HMA) surfaces over a four year period. Results showed good levels of thermoplastic marking retro-reflectivity, tested only on asphalt pavement. Tape was classified as one of the materials that has the longest project service life because it showed almost no change in retro-reflectivity over the testing period on both concrete and asphalt surfaces. Epoxy was only tested on asphalt, and experienced a large decrease in retro-reflectivity *(18)*.

As stated in the previous study, one of the influencing factors of retro-reflectivity is the material of the marking. Aktan and Schnell evaluated three types of markings: a paint with large beads flat marking, patterned tape with high-index beads, and patterned tape with mixed high-index beads. The markings were evaluated under dry, wet, and rainy conditions. The patterned tape with high-index beads produced the highest retro-reflectivity under dry, wet and rainy conditions. Paint with large bead markings gave the lowest retro-reflectivity under dry conditions *(19)*.

Since the visibility of pavement markings impacts safety, an NCHRP study evaluated the relationship between retro-reflectivity and safety over time. The study produced retro-reflectivity models for epoxy, methyl methacrylate, permanent tape, solvent-based paints, thermoplastic and waterborne paint for both white and yellow pavement markings, as a function of climate region and the amount of snow removal. The study found that there is no safety benefit of higher retro-reflectivity for longitudinal pavement markings, although it is important that the markings are present and visible to drivers. One explanation provided in the research is that drivers compensate by reducing their speed under lower visibility conditions. The document provides useful tables to look up retro-reflectivity for the different markings evaluated in different climates *(20)*.

A study conducted in 2010 investigated the correlation between retroreflectivity and crashes. Retroreflectivity was found to be a statistically significant factor in crash probability occurrence. Findings support the NCHRP study, and suggests that an increase in retroreflectivity values increases crash probability on interstate roads. However, when the line type were analyzed in three subsets (white edge line, yellow edge line, and yellow center line), the findings suggested that increasing retroreflectivity values of white edge line and yellow center line decreases crash probability on interstate roads *(21)*. A similar study published in 2012 took place in Michigan to evaluate the relationship between crashes and longitudinal pavement marking retroreflectivity. The findings concluded that maintenance of pavement markings retroreflectifity can have a positive effect on safety. The statistically significant results show that crash frequency during nighttime conditions decreases on two-lane highways as yellow center line or white edge line retroreflectivity increases, and on freeways as yellow edge line and white lane line retroreflectivity increases *(22)*.

#### 2.1.1.3 Other Pavement Markings

Other pavement markings, such as raised pavement markers, wider pavement markings (when used to specifically enhance an area of concern such as a curve in the roadway), and contrasting tapes, are also used to enhance short range delineation.

Pavement markings are not visible when the surface of the roadway becomes wet during adverse weather, particularly on rainy or foggy nights. As an alternative and to ensure visibility during day and night adverse weather, raised pavement markers (RPMs), retroreflective and nonretroreflective, emerged. Raised pavement markers are often used to supplement other markings to provide positive guidance for drivers in inclement weather and low-light conditions. However, RPMs may also be used to substitute for other markings but should simulate the pattern of markings for which they substitute as stated in the MUTCD Section 3B.14. Retroreflective RPMs provide night visibility where there is no overhead lighting and are used in conjunction with painted stripes for longitudinal delineation. Therefore they are particularly desirable at high hazard locations, such as exit ramps, bridge approaches, lane transitions, horizontal curves, and construction zones. Damage from snowplow blades has been the major deterrent to the installation of RPMs in snow areas. Strong adhesion is very critical to RPMs' durability. The major factors that affect pavement bond are:

- properties of the bonding agent;
- design of the RPM's bonding surface;
- type of pavement;
- temperature;
- the care in application; and,
- condition of the existing pavement.

There are different types of RPMs, such as snowplowable raised pavement markers (SRPMs) and light emitting diode (LED) RPMs. NCHRP Report 518 presents findings of a research study that evaluated the safety performance of SRPMs in six different states. The analysis showed that nonselective implementation of SRPMs on two-lane roads does not significantly affect total or nighttime crashes. However, for locations where SRPMs were selectively implemented (e.g. crash history), the results were mixed. This revealed that selective implementation of SRPMs requires careful consideration of traffic volumes and roadway geometry. At low volumes SRPMs can negatively impact safety, which is magnified by the presence of sharp curvature on two-lane roads. On four-lane freeways, the installation of SRPMs show significant reductions for wet weather crashes, and are effective in reducing nighttime crashes where the AADT exceeds 20,000 veh/day *(23)*. In Texas it was found that reflectorized raised pavement markers provided the most preview time under wet-night conditions when compared to the rumble stripe and the use of bigger beads such as Type III, however all these applications improve wet-night detection distance *(24)*. A study of SRPMs that took place in Alberta, Canada found that SRPMs still performed well along the centerline after five years of use. Similar to the FHWA study however, the crash data showed inconclusive results *(25)*. LED RPMs function similar to the standard RPMs, however they operate with a sensor that automatically turns on the LED in dark conditions. There is also the option to wire the LED RPMs to allow an active treatment operation by vehicle detection. Texas has employed this method in advance of horizontal curves to notify approaching drivers who are speeding by activating the flashing operation *(26)*. Currently, this flashing operation does not comply with the MUTCD as described in Sections 3B.11 and 4N.02; the use of flashing in-roadway lights is limited to crosswalks.

Wider pavement markings refers to an increase in marking width over the minimum four-inch standard. A study performed by the Texas Transportation Institute completed in 2012, analyzed the impact of wider 6-inch edge lines on rural two-lane highways both indirectly (by driver opinions, vehicle operations, visibility) and directly (by crash statistics). The results have suggested that wider pavement markings have the potential to reduce total crashes by 15 to 30 percent, and fatal and injury crashes by 15 to 38 percent *(27)*.

Contrasting markings are currently in limited use within Michigan for special markings, but are required where wet reflective preformed tape is placed for lane lines on new Portland cement concrete (PCC) roads. Special markings (arrows, legends) can have contrast by either using bordered tape, or by placing a non-reflective (beadless) black box and then placing the white arrow or legend on top of it. There are two types of applications for longitudinal markings: the bordered design and the shadow design (also referred to as the lead-lag design). The bordered design is a white marking that is highlighted with black markings along the longitudinal sides. The shadow design is a white marking either followed by or preceded by a black marking. The State of Texas evaluated these two types of contrast marking applications. The study showed that some drivers do not understand the meaning of the contrast markings. Drivers also preferred the bordered design, although the shadow design is usually more cost-effective. There was no statistical data to determine if contrast markings increase safety, however the district and state survey respondents believe that the contrast markings provide better visibility on PCC road surfaces *(24)*.

#### 2.1.1.4 Rumble Strips/Stripes

Pavement markings are not the only type of short range delineation. Rumble strips are also considered a form of short range delineation. There are different applications of rumble strips, including shoulder rumble strips, centerline rumble strips, and edge line rumble strips (also referred to as rumble stripes). FHWA has identified rumble strips as a proven countermeasure that reduces the risk of run-off-road crashes. They recommend that rumble strips should be considered system wide on all rural freeways/highways with a posted speed of 50 mph or greater, along rural or urban corridors experiencing run-off-road crashes, and during any highway project with history of run-off-road crashes where the rumble strips have been overlaid. They also require on new and reconstruction projects that four feet of paved shoulder be present beyond the rumble strip *(28)*. NCHRP Report 641, Guidance for the Design and Application of Shoulder and Centerline Rumble Strips, summarizes the best available safety effectiveness for shoulder rumble strips and estimates that crash reduction varies from 11 percent to 51 percent depending on the type of road and crash severity *(29)*.

A synthesis study was recently performed, involving a survey that received 41 responses from state DOT agencies including MDOT. All the responding agencies indicated that they install shoulder rumble strips, with 70% of the agencies stating they install shoulder rumble stripes. The most common type of pavement marking used for the rumble stripes is standard acrylic waterborne paint (42%), followed by epoxy (39%). To maintain the stripe, 85% of the agencies paint over the existing marking, while the remainder off the agencies remove the existing marking prior to reapplication. Twenty-seven percent of the responding agencies confirmed that rumble stripes were being used as a wet night visibility solution *(30)*.

A variant on rumblestripes involved profiled thermoplastic pavement markings. These are a textured thermoplastic which is placed on top of a pavement surface, and is inverted (as compared to typical rumblestrips). Providing audible feedback and improving retroreflectivity in wet conditions, these do not have wide acceptance in snowplow states.

**Figure 1: Profiled thermoplastic pavement markings (source TxDOT)**

## 2.1.2 Long Range Delineation

Long range delineation, such as reflective delineators are effective guidance devices during nighttime and adverse weather conditions. Chapter 3F of the MUTCD states that delineators are particularly beneficial where the alignment of the road may be confusing or unexpected (e.g. horizontal curves, lane-reduction transitions). Long range delineation also includes lighting, alignment signs, and reflective sign posts.

### 2.1.2.1 Lighting

A 2013 NCHRP research study analyzes new highway lighting technologies including the LED source, which has a 'white' color appearance compared to the primary light source in North America which is the high pressure sodium (HPS) lamp, which has a 'yellow' color appearance. The study concluded that

HPS and LED light sources have similar efficiencies, although the LED system demonstrated that efficiency and system costs (based on pole spacing) could be reduced by about 15 percent *(31)*.

In 2015, the Washington State Department of Transportation (WSDOT) performed a study to evaluate the safety performance of continuous roadway lighting on mainline freeway segments. Multivariate random parameter models were developed, along with performing hundreds of literature reviews, to assess continuous roadway lighting. The findings of this study concluded that continuous illumination makes no measurable contribution to nighttime performance and therefore is not warranted to improve safety performance. However, similar to the 2013 NCHRP study, findings from the pilot project indicated that LED roadway lighting can significantly increase energy efficiency *(32)*.

#### 2.1.2.2 Alignment Signs

A 2009 FHWA study was conducted to determine the safety effectiveness of improved curve delineation along two-lane rural roads. Treatments included new chevrons, horizontal arrows, and advance warning signs, as well as the improvement of existing signs using fluorescent yellow sheeting. The results of the study showed that injury and fatal crashes were reduced by 18 percent, and nighttime crashes were reduced by 27.5 percent. Crash reductions were more noticeable at locations with higher traffic volumes and shaper curves with a radii of less than 492 feet, and in locations with more hazardous roadsides. Locations where more signs were either added or replaced with higher retroreflective sheeting also experienced more noticeable crash reductions. The economic analysis showed that improving curve delineation with signing improvements is a cost-effective treatment *(33)*.

The Chevron Alignment Sign (W1-8) may be used to provide advance warning and positive guidance through a horizontal curve. A recent study published by TRB, evaluated the impact of chevrons on vehicle speed and lateral positioning along rural horizontal curves. Two types of chevron installations were evaluated: standard chevrons and chevrons with fully retroreflective posts. There was little difference between the two types of chevron installations. When compared to no chevron installation, findings showed that vehicles moved away from oncoming traffic by about 15 inches and that there was a speed reduction, between 1.25 mph and 2.20 mph depending on type of installation, at locations where chevrons were installed *(34)*. These findings align with the results of a study conducted in 1987 that evaluated the effect of chevrons, among other horizontal alignment treatments, which showed that vehicles moved away from the centerline in nighttime conditions where chevrons were installed *(35)*.

Another treatment that involves the installation of chevron signs are Dynamic Curve Warning and Guidance Systems, which are signs that consist of LED lights that highlight the chevron shape and flash in a sequential manner using wireless communication. As identified by TAPCO, the features and advantages of this guidance system include reduction in speed-related crashes, reduction in head-on and cross-median crashes, roadway departure crash mitigation, and improved curve delineation. The treatment can be further enhanced by installing advance curve warning signs that also utilize the flashing LED signs *(36)*.

#### 2.1.2.3 Delineators/ Reflective sign posts

Post-mounted delineators (PMDs) are capable of providing better delineation during adverse weather conditions and during night time, compared to pavement markings. The purpose of post delineation is to outline the edges of the roadway and to accent critical locations. They are usually mounted on posts at a height of 4 feet (1.2 meters) above the pavement, and provide effectiveness guidance at night and during adverse weather conditions. The retroreflective element should have a minimum dimension of three inches (76 millimeters). The MUTCD provides more details of PMDs.

MDOT's delineator installations consists of two types: rigid steel posts and flexible posts. Flexible delineators are designed to withstand multiple impacts as opposed to rigid steel delineators. They also limit damage to impacting vehicles and potential injury for the occupants. However, the Nevada DOT has experienced excessive replacement and higher life-cycle costs with flexible posts which are not satisfactory. Therefore, they conducted a study to address and mitigate these problems *(37)*. A survey was conducted by WisDOT to identify and evaluate the use of flexible delineators in other states of which 11 responded *(38)*. Survey findings include:

- Three states reported use in right of way marking applications.
- Three states cited advantages in their use instead of steel posts:
  - Flexible delineators are resilient to impact;
  - Not as damaging to vehicles (including motorcycles); and,
  - Typically require less maintenance and provide a longer service life when placed in an area with frequent "hits".
- Three states provided disadvantages in their use of flexible delineators:
  - Higher purchase cost; and,
  - Susceptible to destruction by roadside mowers and plowed snow.
- Seven states reported that reflective tape or sheeting provides visibility that is comparable to or better than prismatic reflectors.

A study conducted at four sites in rural Texas evaluated standard post-mounted delineators with a single reflector on top and fully retroreflective post-mounted delineators. The results showed both types of delineation improve vehicle lane position and reduce encroachment, although fully retroreflective post-mounted delineators performed slightly better *(39)*.

### 2.1.3 Other Delineation Systems

Other delineation innovations in use in other jurisdictions that may potentially benefit Michigan are colored shoulder pavement, painted medians, and gateway treatments.

A study was conducted to evaluate the effect of painted shoulders on vehicle speeds in Ithaca, New York. The results showed that the effect of colored shoulders on speed is minimal. There was a slight increase in speed, approximately one mile per hour, for trucks *(40)*. Painted shoulders are often used in as part of a gateway treatment in Europe to provide a visual cue that they have transitioned into a different area. Gateway treatments are typically used on highways and county roads that transition into slower speed roads through rural communities. Research was conducted in Iowa to evaluate the use of two gateway treatments that included a combination of enhanced signing, lane narrowing, colored pavements, pavement markings, experimental striping, gateway structures, and traditional traffic calming techniques. Some of these treatments were shown to reduce speeds *(41)*.

The safety benefit of a continuous narrow painted median strip on an undivided rural highway was evaluated in Queensland, Australia. The painted median was one meter wide and included rumble strips. Findings indicated that total crashes were reduced by 59 percent, and head-on crashes were reduced by 75 percent *(42)*.

Other types of delineators used to supplement standard pavement markings include:

- *object markers* – identify obstructions within or adjacent to roadway
- *warning signs* – supplement pavement markings (e.g., Advisory Speed plate, Large Arrow and Chevron Alignment signs)
- *barrier delineators* - retroreflective units that mount on guardrails, concrete barriers, and bridge parapets.
- *pavement symbols* - word and symbol markings on the pavement. MDOT, however, considers this type of marking as a standard pavement markings.

Other treatments for improving delineation and awareness of the roadway may not require traffic control devices. For instance, improving clear zones and trimming back vegetation – especially on the inside of a curve – will better allow a driver to recognize the change in horizontal alignment. This type of a delineation strategy does not include a traffic control device that could potentially be damaged by a driver.

## 2.2 Summary of State-of-the-Art

*The Roadway Delineation Practices Handbook (1)* defines delineation as one device, or a combination of control devices, which regulate, warn, or provide tracking information and guidance to the driver. Delineation used must also be visible in daylight and darkness, as well as in periods of adverse weather such as rain and fog. Based on the literature review and survey, which will be discussed on more detail in the report, a series of state-of-the-art delineation practices have been identified and are summarized below. While this list strives to be representative, it is not necessarily all inclusive.

- Delineation programs should include both long and short range delineation to supplement each other and other guidance as appropriate.
  - Examples of short range delineation include:
    - longitudinal lines;
    - other pavement markings; and,
    - rumble strips.
  - Examples of long range delineation include:

        - mainline lighting;
        - reflective delineators; and,
        - reflective sign posts for horizontal alignment signs.
- Pavement Marking Materials & Practices
    - The primary types of materials used for marking in the U.S. include:
        - Waterborne paints;
        - Conventional solvent paints;
        - Thermoplastic;
        - Preformed Tape;
        - Epoxy;
        - Methyl methacrylate;
        - Polyester; and,
        - Polyurea.
    - Both durable and non-durable pavement marking materials have been shown to be cost effective in different situations.
        - A study in Minnesota has shown that for roads with AADT of 10,000 or less, paint may be the most cost-effective material while a more durable product such as epoxy or preformed tape may be more appropriate for roads with AADT greater than 10,000 *(43)*.
    - Use of durable and non-durable pavement markings should be based on several factors including, at a minimum:
        - Cost;
        - Pavement Condition / Remaining Service Life; and,
        - AADT.
    - For installations of durable pavement markings, significant consideration should be given to recessing the markings to improve longevity.
    - Preformed wet reflective tapes provide more reflectivity than non-wet reflective tapes
        - Due to cost, it is generally recommended that wet reflective tape only be used for freeway broken and dotted lane lines and requires preformed shadow tape if installed on concrete.
    - Durable pavement marking materials have been shown to be good alternatives to traditional waterborne paints in cold climates. The following was identified in Alberta, Canada:
        - This is especially true when the markings are recessed or used with rumble stripes.
        - It is recommended to consider installation on:
            - Four-lane divided highways with AADTs greater than 15,000;
            - Rural two-lane highways with AADTs greater than 5,000; and,
            - Urban two-lane undivided highways with AADTs greater than 8,000.

- Other types or variations of pavement markings which have been shown to have a positive effect on delineation visibility include:
  - Raised pavement markers / Snowplowable raised pavement markers, either reflective or active LED[1]
    - Greatest positive impact tends to be realized when implemented at targeted locations such as exit ramps, bridge approaches, lane transitions, horizontal curves, and construction zones.
    - Improves wet and night time visibility
  - Wider pavement markings, and;
    - Studies suggest wider pavement markings have been associated with a 15 to 38 percent reduction in fatal and injury crashes *(27)*.
  - Contrast tapes (helps white pavement markings stand out against concrete pavements).
    - No statistical data is currently available but it is widely accepted that contrast markings improve marking visibility on concrete pavements.

- Physical Delineation Materials & Practices
  - Rumble Strips are a proven countermeasure for the reduction of run-off-road and other lane departure crashes *(28)*.
    - FHWA recommends blanket application on all rural freeways and highways with a posted speed limit of 50mph or greater or areas where there is a significant crash history supporting their use.
    - Rumble stripes consist of the inclusion of a painted marking stripe along the length of the rumble strips and have been shown to improve wet and night time visibility of the pavement marking.
  - Lighting
    - LED roadway lighting has been shown to reduce costs through improved energy efficiency and tower / post placement.
      - Improved safety performance has not been noted above and beyond standard lighting practices.
  - Alignment Signs
    - Studies have shown that chevrons, horizontal arrows, and advance warning signs, as well as the improvement of existing signs using fluorescent yellow sheeting on two-lane rural roads, improve safety *(33)*.
      - Associated economic analyses showed that these types of curve delineation improvements can be a cost-effective treatment.
    - Dynamic Curve Warning and Guidance Systems are signs that employ LED lights to highlight the sign and flash in a sequential manner using wireless communication

[1] Currently in use in Texas but this practice is out of compliance with the MUTCD

        - Noted reductions in speed-related crashes, reduction in head-on and cross-median crashes, roadway departure crash mitigation, and curve delineation.
    - Delineators / Reflective Sign Posts
        - Rectangular reflective sign sheeting has increased in use and is being shown to be more resilient to strikes than the more traditional reflective buttons.
        - Flexible delineator posts have also been shown to possess some advantages over traditional steel posts. These include:
            - Flexible delineators are resilient to impact
            - Not as damaging to vehicles (including motorcycles)
            - Typically require less maintenance and provide a longer service life when placed in an area with frequent "hits"
        - It should be noted that flexible delineator posts tend to have a higher purchase cost and are more prone to damage or destruction when exposed to maintenance equipment.
        - Fully reflective post mounted delineators have been shown to have a slightly improved performance over a single reflective piece at the top of the post.
- Other Delineation Systems / Variations
    - Narrow continuous painted median strip has been shown to have a positive effect in the reduction of head-on crashes.
    - Physical and painted delineation measures may be supplemented by other practices which enhance their visibility, including maintenance of clear zones and sight triangles, reviewing and updating sign placement, and other maintenance activities to keep reflective surfaces clear and unobstructed.

## 2.3 Critical Factors

There are a few documents that identify key influencing factors, as cited in the sections below, which should be considered when identifying a delineation system. These factors include: geometry, pavement surface, lighting, climate, winter maintenance, speed, traffic conditions, roadway functional classification, and human factors.

### 2.3.1 Geometry

Depending on the geometry of the road, whether it be a tangent section, horizontal curve, merging/diverging area, etc., different delineation techniques are required.

The FHWA handbook cited that many studies indicate the presence of edgelines on tangent sections decrease variability in lateral placement, however the average lateral placement shifts towards the centerline. Therefore, many states prohibit edgeline pavement markings on roads narrower than 18 feet.

Enhanced delineation is typically installed along horizontal curves. The MUTCD requires horizontal alignment warning signs in advance of horizontal curves on freeways, on expressways, and on roadways with more than 1,000 AADT. Table 2C-5 from the MUTCD, shown in Figure 2, outlines the requirements for sign type based on the differential speed between speed limit and advisory speed.

**Table 2C-5. Horizontal Alignment Sign Selection**

| Type of Horizontal Alignment Sign | Difference Between Speed Limit and Advisory Speed | | | | |
|---|---|---|---|---|---|
| | 5 mph | 10 mph | 15 mph | 20 mph | 25 mph or more |
| Turn (W1-1), Curve (W1-2), Reverse Turn (W1-3), Reverse Curve (W1-4), Winding Road (W1-5), and Combination Horizontal Alignment/Intersection (W10-1) (see Section 2C.07 to determine which sign to use) | Recommended | Required | Required | Required | Required |
| Advisory Speed Plaque (W13-1P) | Recommended | Required | Required | Required | Required |
| Chevrons (W1-8) and/or One Direction Large Arrow (W1-6) | Optional | Recommended | Required | Required | Required |
| Exit Speed (W13-2) and Ramp Speed (W13-3) on exit ramp | Optional | Optional | Recommended | Required | Required |

Note: Required means that the sign and/or plaque shall be used, recommended means that the sign and/or plaque should be used, and optional means that the sign and/or plaque may be used.

**Figure 2: Horizontal Alignment Sign Selection**
**(Source, MUTCD)**

#### 2.3.1.1 Pavement Surface

The pavement surface generally impacts the type of pavement marking to be used and the durability of the pavement marking. The life of the pavement is also significant when considering durable pavement markings, such as RRPMs or thermoplastic markings.

The Texas Transportation Institute (TTI) conducted research to identify pavement marking best practices on concrete roadways *(44)*. Two important measures for pavement markings include durability and visibility (retroreflectivity and contrast). Performance may vary greatly due to roadway surface, traffic volume, and weather. A survey was completed to identify the best materials for pavement markings on concrete.

Several materials are described in terms of use on concrete roadways, including:

- Thermoplastic
    - Most frequently used in Texas due to availability (material and contractor), cost, and performance
    - May prematurely de-bond from concrete – surface preparation before application is important as well as material quality
- Epoxy

    - A two component paint that is sprayable and bonds well to asphalt and concrete
    - Has long drying time and not widely used
    - Performance depends on surface preparation, color stability under UV exposure, and length of curing time
- Permanent Preformed Tape
    - Long service life, high retroreflectivity, and strong bonding between asphalt and concrete
    - Considerations should be made for initial material cost and the existing service life of the roadway
    - Performance depends on air/surface temperature and moisture during application, surface preparation, adhesive quality, and curing time
- Polyurea
    - Two component, outperforms traditional paint and epoxy
    - Proponents cite color stability, drying quickly, application in low temperature, no impact from humidity, and bonding well to both asphalt and concrete
    - high application cost has been cited
- Other Materials
    - Methyl Methacrylate (MMA) – can be applied in low temperatures, resistant to chemicals, and bonds well to asphalt and concrete; but expensive, limited experience (not widely used), long dry time, and requires special equipment
    - Modified Urethane – two component, similar to epoxy; not widely used (limited experience), very short cure time
    - Waterborne Paints – widely used and inexpensive, long dry time, not suitable for high traffic volume concrete roadways
    - Ceramic Buttons – only used in areas without snow removal; non-retroreflective, must be supplemented by RRPMs
- Visibility Enhancing Pavement Markings
    - Profiled pavement markings – no snow removal areas, provide visibility at night and wet conditions
    - Contrast pavement markings – white markings supplemented by black base material to increase contrast to roadway

Based on the research findings, recommendations include:

- Use epoxy materials for long-term applications under the majority of traffic conditions
- Use preformed tape for long-term applications under very heavy traffic
- Use specified thermoplastic only for short-term applications with low to medium traffic

The Minnesota Department of Transportation conducted research to evaluate pavement markings on challenging road surfaces *(45)*. Challenging road surfaces consisted of seal coat and micro surface roadway. The testing materials consisted of Latex, High build paint, and Epoxy. Latex at a 12 mil thickness failed in less than one year. High build paint at 25 mil thickness with primer performed similarly as the two Epoxy materials (HPS4 & MFUA-10) used at 12 mil thickness which performed well after two winter seasons.

A few states also consider the condition of the pavement when installing rumble strips, with some stating that rumble strips are not installed on PCC pavements.

#### 2.3.1.2 Lighting

The FHWA Lighting Handbook is a resource that identifies the potential need and benefits of a roadway lighting system *(46)*. To analyze the need for lighting, the document references the *AASHTO Roadway Lighting Design Guide Warranting System* for highways/freeways/interchanges/bridges, and the *Transportation Association of Canada (TAC) Guide for the Design of Roadway Lighting* for collector/major/local streets. The AASHTO warrants are based on traffic volumes, spacing of freeway interchanges, lighting in adjacent areas, and night-to-day crash ratio *(47)*. The TAC warrants are based on the following factors: geometric, operational, environmental, and night and day crashes *(48)*. Benefits of lighting are that it significantly improves the visibility of the roadway, increases sight distance, and makes roadside obstacles more noticeable to the driver. Many studies have also found that lighting has been proven to reduce crashes. The FHWA Lighting Handbook states, "If the night-to-day crash ratio is 2:1 or greater, lighting is automatically warranted regardless of the overall point-score".

#### 2.3.1.3 Climate

A study that took place in New Zealand evaluated driver risk perceptions in road visibility using the 'hands-on' method. The 'hands-on' method compared differences in driver behavior (speed, headway or hand positions) between dry daytime conditions and wet or nighttime conditions. Wet road conditions showed the highest level of perceived risk when compared to dry daytime or dry nighttime conditions. Drivers also traveled slower on wet road conditions. The study recommended that treatments for delineation on wet road conditions should be given more priority than nighttime conditions *(49)*. Adverse weather conditions, such as rain, makes driving difficult as proven in the previous study. Therefore, enhanced delineation systems, such as more reflective pavement markings, are needed to improve roadway delineation in adverse weather conditions. The use of large glass beads or elements in water base paint, epoxy, polyester, and thermoplastic marking material can provide for all weather pavement markings.

Since Michigan also experiences snowy weather conditions, delineation techniques that are visible in snowy conditions should also be considered (e.g. RPMs and post-mounted delineators). As stated in the FHWA handbook, RPMs and post-mounted delineators are effective for all weather conditions. The pavement markings used should also be designed to withstand cold temperatures.

#### 2.3.1.4 Winter Maintenance

Studies have found that the durability and retro-reflectivity of pavement markings can be extend by recessing the durable pavement markings to protect from snowplow wear, applying markings on rumble strips (i.e. rumble stripes), and installing SRPMs *(11) (12)*. SRPMs selectively installed on four-lane freeways that experience a crash history could potentially reduce wet weather crashes and nighttime crashes where the AADT exceeds 20,000 veh/day *(23)*.

#### 2.3.1.5 Speed

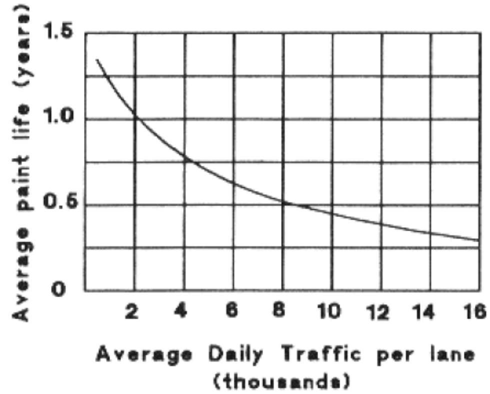
Visibility models were developed to achieve a minimum of two seconds of preview time for short range delineation, which aligns with values established in an FHWA Techreport *(50)*, and three to ten seconds of preview time for long range delineation, which aligns with research published by the Society of Automotive Engineers *(51)*. These minimum viewing times were also cited in the *FHWA Roadway Delineation Practices Handbook*. In an NCHRP Synthesis report, the same preview time of two seconds was found to be the minimum acceptable limit on roads with properly maintained pavement markings and RRPMs. A preview time of three seconds was recommended to provide long-range guidance information, which must be seen at least 243 feet ahead when traveling at 55 mph *(10)*.

In a study published by the Transportation Research Institute, preview times vary slightly. The conclusion of the study found that short range guidance requires a preview time of up to three seconds, and long range guidance requires a preview time of at least five seconds *(52)*. The study also concludes that drivers rely only on short range delineation when visibility is degraded, particularly in nighttime or rainy weather conditions. Another study looked at ways to improve long range guidance in dark conditions. Results stated that, "A combination of lane markings and post-mounted delineators might be optimal for night guidance, with lane markings assisting in short range guidance and post-mounted delineators assisting in long range guidance" *(53)*.

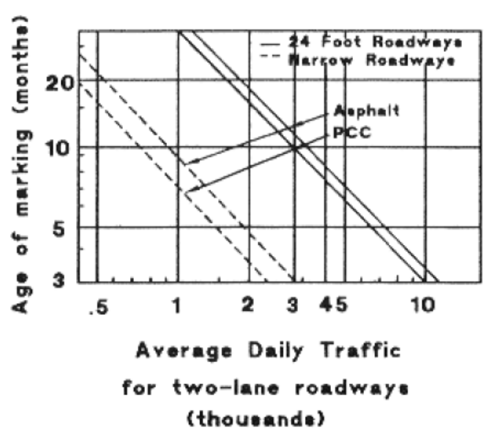
Transverse rumble strips have been used to slow speeds and can be considered as a delineation measure to warn drivers of upcoming changes in the roadway through audio-tactile means. This application is generally used in advance of a stop controled intersection, however the MUTCD states that it can also be applied in conditions requiring a reduction in speed.

#### 2.3.1.6 Traffic Conditions

Traffic volumes are usually considered when determining the type of pavement markings to be used. Since roads with higher traffic volumes or a high percentage of heavy vehicles may wear out the markings quickly, a more durable marking should be considered. This reduces frequent maintenance and exposure of crews to traffic. An example from the FHWA handbook demonstrates the correlation between ADT and service life shown in Figure 3.




a) Paint striping as affected by traffic density for both bituminous and concrete pavement (Ref. 29)




b) Conditions for noticeable traffic stripe wear (white traffic paint placed at 15 mile wet with 6 pounds of beads per gallon) (Ref. 29)

**Figure 3: Effect of ADT on service life of thermoplastic markings (Source, FHWA Handbook)**

The Roads and Transport Authority (RTA) provides some general guidelines for implementing delineation based on the environmental condition and AADT, shown in Figure 4 *(14)*.

| MINIMUM AADT | **Basic Level of delineation**<br>(For installation guidelines and specifications of individual delineation devices, refer to the relevant sections in the guidelines) |
|---|---|
| All Rural roads | • Guide posts |
| • 300 | • Guide posts<br>• Dividing lines |
| • 750 | • Guide posts<br>• Dividing lines<br>• Edge lines |
| • 3,000 | • Guide posts<br>• Dividing lines<br>• Edge lines<br>• Reflective pavement markers on centreline<br>• Full treatment at intersections, auxiliary lanes and substandard horizontal curves |
| • 5,000 | • Guide posts<br>• Dividing lines<br>• Edge lines<br>• Reflective pavement markers on centreline and edge lines<br>• Full treatment at intersections, auxiliary lanes and substandard horizontal curves |

**Table 19.1:** Delineation level based on AADT (Rural Conditions)

Notes:
(a) Table gives the minimum level of delineation
(b) Some roads may require reduced volume warrants or some devices may require additional warrants before they are installed – refer to the main section in the guidelines
(c) Full treatment means the provision of all the delineation devices, if warranted.

| MINIMUM AADT | **Basic Level of delineation**<br>(For installation guidelines and specifications of individual delineation devices, refer to the relevant sections in the guidelines) |
|---|---|
| • 2,500 | • Dividing lines |
| • 4,000 | • Dividing lines<br>• Edge lines |
| • 6,000 | • Dividing lines<br>• Edge lines<br>• Reflective pavement markers on centreline<br>• Full treatment at significant intersections, auxiliary lanes and substandard horizontal curves |
| • 10,000 | • Dividing lines<br>• Edge lines<br>• Reflective pavement markers on centreline and edge line<br>• Full treatment at significant intersections, auxiliary lanes and substandard horizontal curves |

**Table 19.2:** Delineation Level Based on AADT (Urban conditions)

Notes:
(a) Table gives the minimum level of delineation
(b) Some roads may require reduced volume warrants or some devices may require additional warrants before they are installed – refer to the main section in the guidelines
(c) Full treatment means the provision of all the delineation devices, if warranted.

**Figure 4: Delineation level based on AADT, Rural Roads Vs. Urban Roads (Source, RTA)**

NCHRP Report 518 identifies where to install RPMs based on the roadway environement, degree of curvature, and the AADT. These guidelines are shown in Table 2 and Table 3, where CMFs equal the expected number of crashes with RPMs over the expected number of crashes without RPMs.

**Table 2: CMFs for two-lane roadways, nighttime crashes (Source, NCHRP Report 518)**

| AADT (veh/day) | CMF | |
|---|---|---|
| | When DOC ≤ 3.5 | When DOC > 3.5 |
| 0–5000 | 1.16 | 1.43 |
| 5001–15000 | 0.99 | 1.26 |
| 15001–20000 | 0.76 | 1.03 |

DOC = degree of curvature.

**Table 3: CMFs for four-lane freeways, nighttime crashes (Source, NCHRP Report 518)**

| AADT (veh/day) | CMF |
|---|---|
| ≤ 20000 | 1.13 |
| 20001–60000 | 0.94 |
| > 60000 | 0.67 |

#### 2.3.1.7 Roadway functional classification

No literature was found indicating roadway functional classification as an influencing factor to determine the type of delineation. However, the environment (i.e. urban versus rural) is typically used to determine measures of delineation.

#### 2.3.1.8 Human Factors

As detailed in the *FHWA Roadway Delineation Practices Handbook (1)*, the driver's ability to operate a vehicle safely is based on the driver's perception of a situation, level of alertness, the amount of information available, and the driver's ability to assimilate the information. This can be a challenge for drivers with greater visibility needs (e.g. older drivers). To accommodate drivers with limited vision, the use of brighter delineators to increase visibility distances and additional delineation to increase available information are needed.

Older drivers require more light to see delineation and are slower to react. The NCHRP Synthesis 306 report states that older drivers cannot be accommodated at all speed levels with pavement markings, however the additions of RRPMs makes it possible to accommodate most drivers.

# 3 Methodology

## 3.1 Documents

The Michigan Department of Transportation relies on a number of standards, documents to maintain relevant delineation system requirements and inventories. The following provides a brief overview of a number of related information sources.

- Delineator Usage Guidelines (*54*)
    - Provides guidance and instruction for use of roadside, guardrail, and barrier delineators for MDOT projects. Information provided includes project types where delineation or enhanced delineation may be used or where it is required, types of delineators to be used, and reference to specific sections of the Road Design Manual and Roadway Standard Plans. Other references include links to other design guidelines, special plans, and a calculation spreadsheet. It must be noted that the links included in the document are no longer current.
- Michigan MUTCD (*55*)
    - The Michigan Manual on Uniform Traffic Control Devices (MMUTCD) covers a wide range of traffic control types and scenarios. Information in this document relevant to this report includes guidance for pavement markings for general traffic management, highway traffic control, low-volume road traffic control, temporary traffic control, school area traffic control, railroad and light rail traffic control, and bicycle facility traffic control. Pavement marking information includes guidance for long line as well as special markings.
- Pavement Marking Guidelines
    - Provides a series of standard details for permanent pavement markings for various geometric scenarios including freeways and ramps, intersection markings, shared lane, and parking areas, among others. Information contained in these guidelines has been updated as recently as 2015.
- Road Design Manual (*57*)
    - The Road Design Manual provides standard guidance regarding a number of roadway related projects including plan preparation and log projects. Of particular interest for this report is section 1.02.18 – Pavement Marking Plans. This section provides specific requirements for pavement marking plans, associated information as to how this information should be displayed, and where to find standard plans for pavement markings.

- Standard Specifications for Construction – 2012 (*58*)
    - 810 – Permanent Traffic Signs and Supports
        - Provides details for the materials, construction, measurement and payment to fabricate and erect traffic signs and supports in accordance with the MMUTCD, the Michigan Standard Highway Signs Manual, and the Department Sign Support Standards.
    - 811 – Permanent Pavement Markings
        - Provides information on applying retroreflective permanent pavement markings in accordance with the MMUTCD. This includes markings, shapes, spacing, and dimensions that conform to the MDOT Pavement Marking Standard Plans.
    - 822 – Ground or Cut Shoulder Corrugations
        - Provides details for construction of milling or diamond grinding corrugations (rumble strips) into finished hot mix asphalt or concrete highway shoulders.
    - 918 – Electrical and Lighting Material
        - Provides minimum specifications for several luminaire systems and associated hardware. Examples of specifications included in the document cover maintenance hand holes, conduit and other wiring, support structures, and various lighting systems.
    - 919 – Permanent Traffic Sign and Support Materials
        - Provides general signing specifications as well as delineator-specific requirements. Information includes post, mounting hardware, reflective sheeting, plastic reflectors, and their optical performance requirements.
    - 920 – Permanent Pavement Marking Materials
        - Provides glass bead requirements for various application types, including use with standard and low temperature waterborne, regular dry, thermoplastic, sprayable thermoplastic, and polyurea marking materials.
- MDOT Special Provisions (*59*)
    - 810 Permanent Traffic Signs and Supports
        - Rectangular Delineator Reflectors, Sheeted

        - Provides guidance regarding the materials, construction, measurement and payment information for the installation of rectangular delineator reflectors.

    - 811 Permanent Pavement Markings

        - Provides guidance regarding the materials, construction, measurement and payment information for the installation of:

            - Bidirectional - Concrete Barrier Side Mount
            - Bidirectional - Concrete Barrier Top Mount
            - Bidirectional - Guardrail Channel Mount
            - Bidirectional - Guardrail Post Mount
            - Enhanced Linear Delineation
            - Pavement Markings on, CPM; Cold Mill & One Course HMA Overlay & One Course HMA Overlay Projects
            - Polyurea Surface Preparation with Existing Polyurea Markings
            - Raised Island Painting
            - Unidirectional - Concrete Barrier Side Mount
            - Unidirectional - Concrete Barrier Top Mount
            - Unidirectional - Guardrail Channel Mount
            - Unidirectional - Guardrail Post Mount

## 3.2 GIS & Data Inventories

Inventories of existing data and GIS information were gathered and reviewed for long line pavement marking, special pavement marking, guardrail, lane mile, high mast lighting, and rumble strip. Any gaps in the data inventories have been identified and noted below. The data, where applicable, was used to estimate costs related to upgrading/replacing delineation components.

- Long Line Pavement Marking Inventory

    - The Long Line Pavement Marking Inventory provides a detailed record of the long line pavement marking locations on MDOT-maintained routes and properties. These include trunkline infrastructure as well as rest areas and park and ride lots, among others. Information reported for each line item includes jurisdictional information, location information in the form of control sections and mile points, general location descriptions, marking length, color and width of each marking, and comments providing additional information as required. The information is available in an Excel format and can be imported into GIS based systems using a linear referencing system. It should be noted that, as of the date of this report, roughly a third of the line items were missing location information.

- Special Pavement Marking Inventory
    - The Special Pavement Marking Inventory provides a detailed record of special pavement marking locations on MDOT-maintained routes and properties. These include trunkline infrastructure as well as rest areas and park and ride lots. Information reported for each line item includes jurisdictional information, location information in the form of control sections and mile points, general location descriptions, marking symbol or message, color, and comments providing additional information as required. The information is available in an Excel format and can be imported into GIS based systems using a linear referencing system. It should be noted that, as of the date of this report, roughly a third of the line items were missing location information.
- Guardrail Inventory
    - The MDOT guardrail inventory is available through the GIS portal for the State of Michigan. The information spatially locates runs of guardrail located along MDOT-maintained routes. Attributes included for each instance of guardrail include identifying numbers for each run of guardrail, identifying information regarding the roadway the run is located along, the types of approach and departure treatments, material, condition, the purpose for each run of guardrail, its height, and physical reference number and mile point information. It must be noted that guardrail information is missing for nineteen southern counties.
- Lane Mile Inventory
    - The MDOT lane mile inventory is available through the GIS portal for the State of Michigan. The shapefile spatially locates MDOT-maintained routes and includes attributes for each instance including the number of lanes, presence of bike lanes, jurisdictional / maintenance information, speed limit, presence of sidewalks and parking, and the Region the segment is located in. The shapefile appears to be complete and is updated on a yearly basis.
- High Mast Lighting Inventory

- Information for the location of some portion of high mast lighting maintained by MDOT was made available to the research team in and Excel format. This information was imported into a GIS system where corrections were made to the geolocation information for several instances. The records were created during maintenance activities and do not represent a complete inventory of high mast lighting in the state.

- Three types of errors were noted during the review of the Lighting Inventory, namely missing locations, incomplete inventory, and transpositional errors. Examples of these three error types follow.

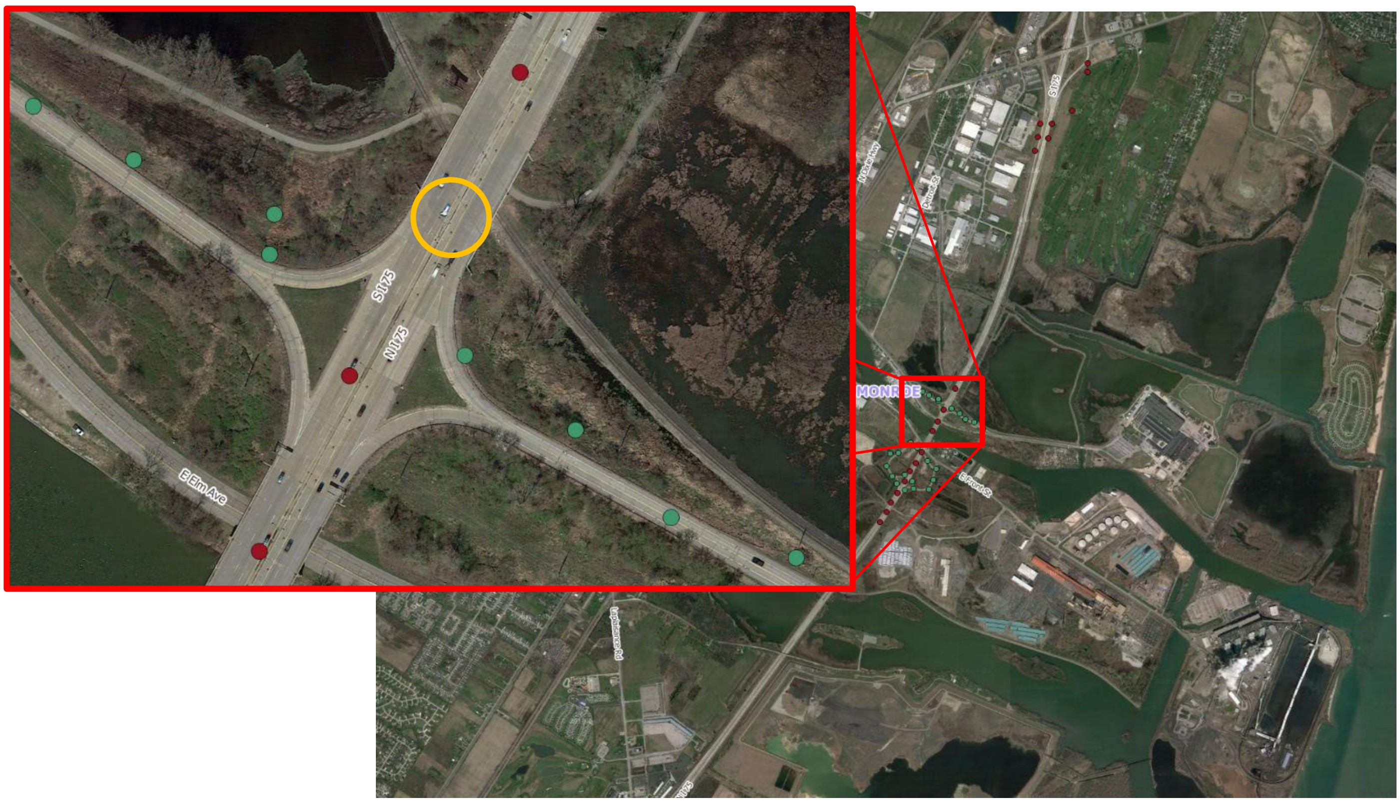



**Figure 5: Example of missing location**

In Figure 5, the orange circle indicates a missing inventory feature within a series of regularly spaced features.

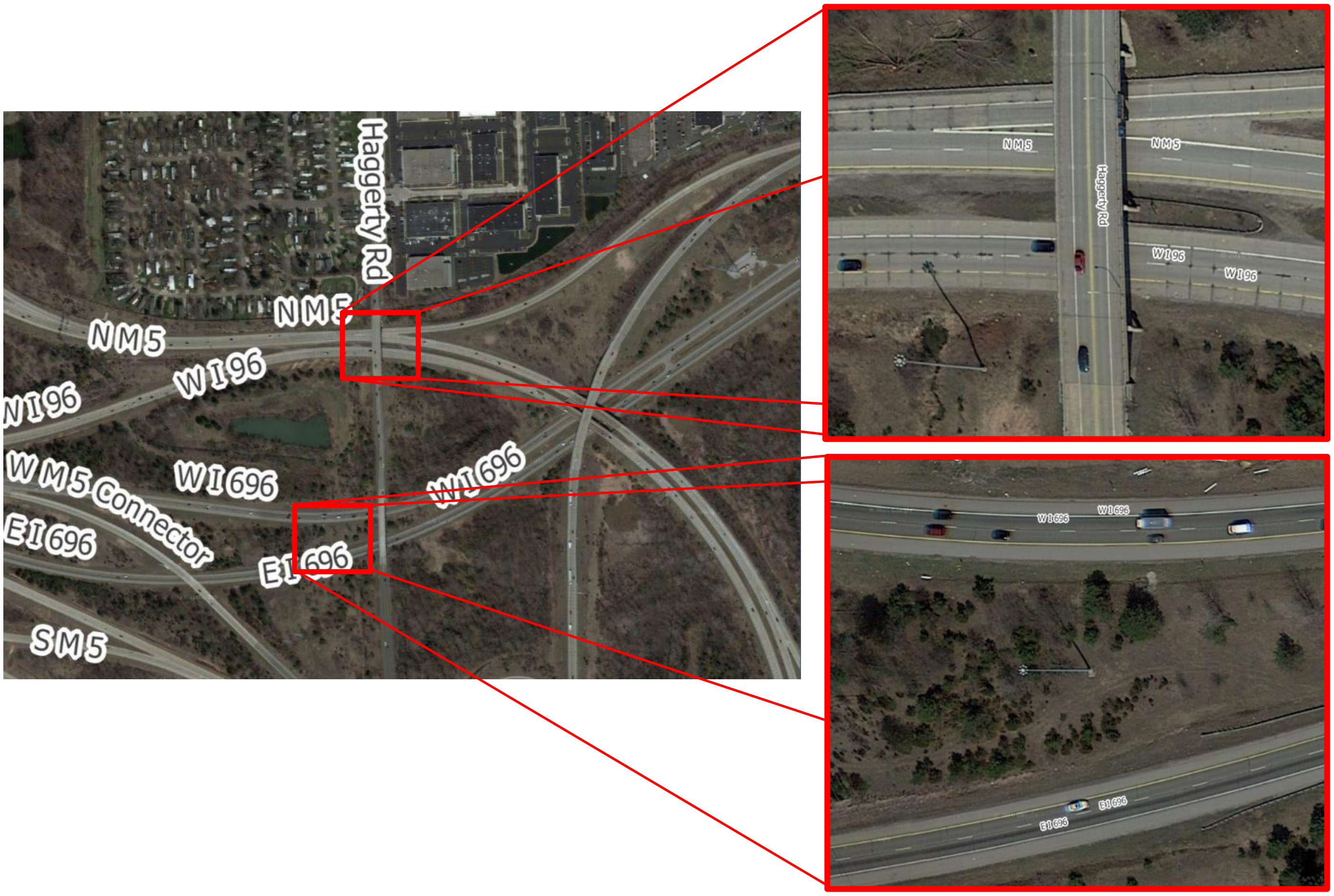
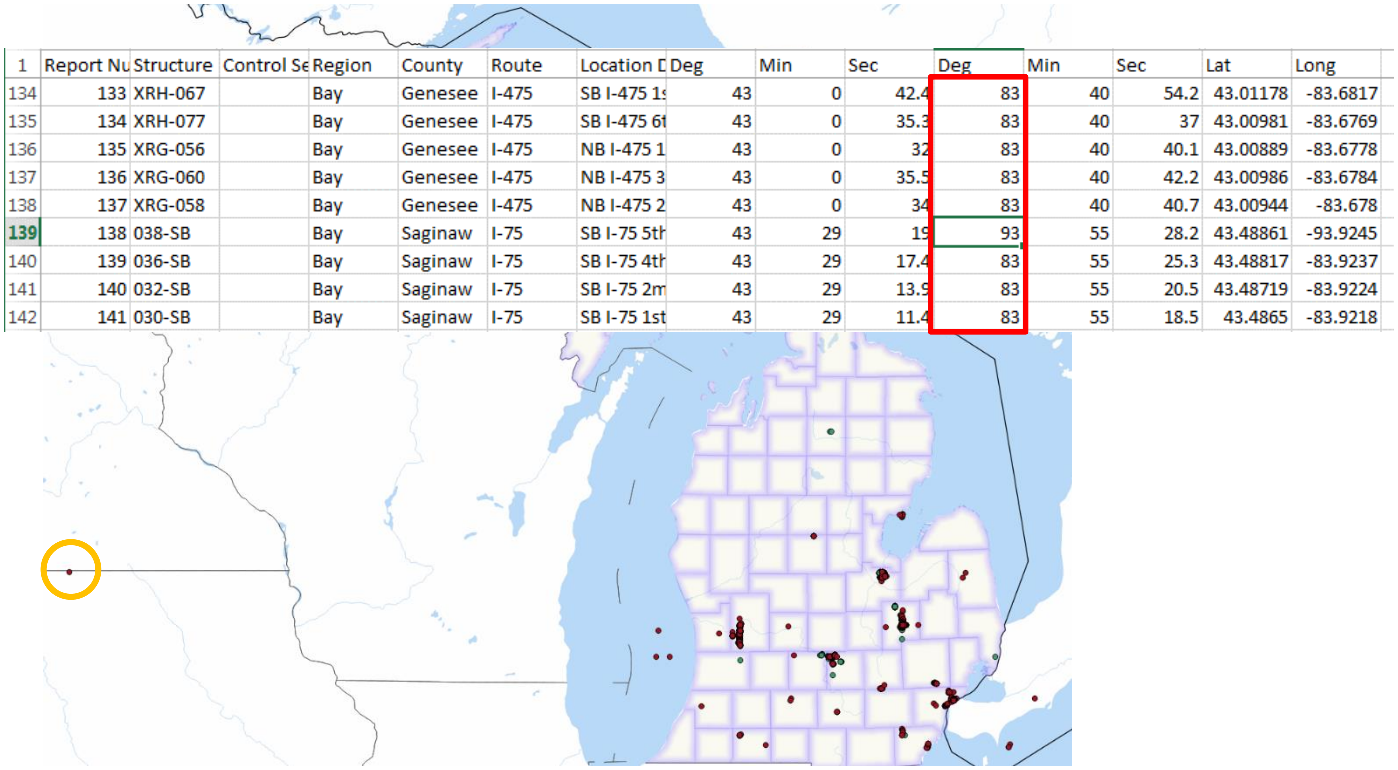



**Figure 6: Example of incomplete inventory**

Figure 6 shows an example of the incomplete inventory, where high-mast lights visible from field or aerial map review are not present in the inventory.



| 1 | Report Nu | Structure | Control Se | Region | County | Route | Location D | Deg | Min | Sec | Deg | Min | Sec | Lat | Long |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 134 | 133 | XRH-067 | | Bay | Genesee | I-475 | SB I-475 1s | 43 | 0 | 42.4 | 83 | 40 | 54.2 | 43.01178 | -83.6817 |
| 135 | 134 | XRH-077 | | Bay | Genesee | I-475 | SB I-475 6t | 43 | 0 | 35.3 | 83 | 40 | 37 | 43.00981 | -83.6769 |
| 136 | 135 | XRG-056 | | Bay | Genesee | I-475 | NB I-475 1 | 43 | 0 | 32 | 83 | 40 | 40.1 | 43.00889 | -83.6778 |
| 137 | 136 | XRG-060 | | Bay | Genesee | I-475 | NB I-475 3 | 43 | 0 | 35.5 | 83 | 40 | 42.2 | 43.00986 | -83.6784 |
| 138 | 137 | XRG-058 | | Bay | Genesee | I-475 | NB I-475 2 | 43 | 0 | 34 | 83 | 40 | 40.7 | 43.00944 | -83.678 |
| 139 | 138 | 038-SB | | Bay | Saginaw | I-75 | SB I-75 5th | 43 | 29 | 19 | 93 | 55 | 28.2 | 43.48861 | -93.9245 |
| 140 | 139 | 036-SB | | Bay | Saginaw | I-75 | SB I-75 4th | 43 | 29 | 17.4 | 83 | 55 | 25.3 | 43.48817 | -83.9237 |
| 141 | 140 | 032-SB | | Bay | Saginaw | I-75 | SB I-75 2m | 43 | 29 | 13.9 | 83 | 55 | 20.5 | 43.48719 | -83.9224 |
| 142 | 141 | 030-SB | | Bay | Saginaw | I-75 | SB I-75 1st | 43 | 29 | 11.4 | 83 | 55 | 18.5 | 43.4865 | -83.9218 |

Figure 7: Example of transpositional error

Transpositional errors are shown in Figure 7. These may occur when inventory updates are made from manual data collection (e.g. paper forms) rather than automated collection. Transpositional errors, where apparent, were corrected in the database and returned to MDOT to update their records.

- Rumble Strip Inventory (WSU Research)

During previous research for MDOT, a Wayne State University research team compiled a record of center and edgeline rumble strips throughout the state. Information in this inventory includes the physical reference number and mile points along the route the rumble strips are located on as well as lat / long coordinates, number of lanes along each route, the installation date of the rumble strips, physical characteristic for the route, the type, width, and condition of shoulders, as well as volumes and crashes associated with each segment. It is not known if the inventory is complete.

## 3.3 Practitioner Survey

### 3.3.1 Survey Methodology

To ensure sufficient participation by other states, the research team addressed the survey in three stages. The first stage involved contacting other states to identify appropriate section/contact person(s) suitable for the survey. Once these contacts were confirmed, the second stage consisted of distributing the survey (via QuestionPro.com); the text of which is provided in an appendix to this report. The survey was distributed by email to the appropriate section/contact person(s) identified in the first stage. The third stage included a series of follow up conversations via telephone for clarification and collection of additional detailed information. Survey findings are presented in section 5.3 Presentation of Results.

### 3.3.2 Survey Results

#### 3.3.2.1 Survey Participants

In total, 20 states and two provinces contributed to the road delineation survey as indicated in Figure 8. The majority of the states that participated were within the Midwest. All states neighboring Michigan submitted responses, including Minnesota, Wisconsin, Illinois, Indiana, and Ohio.

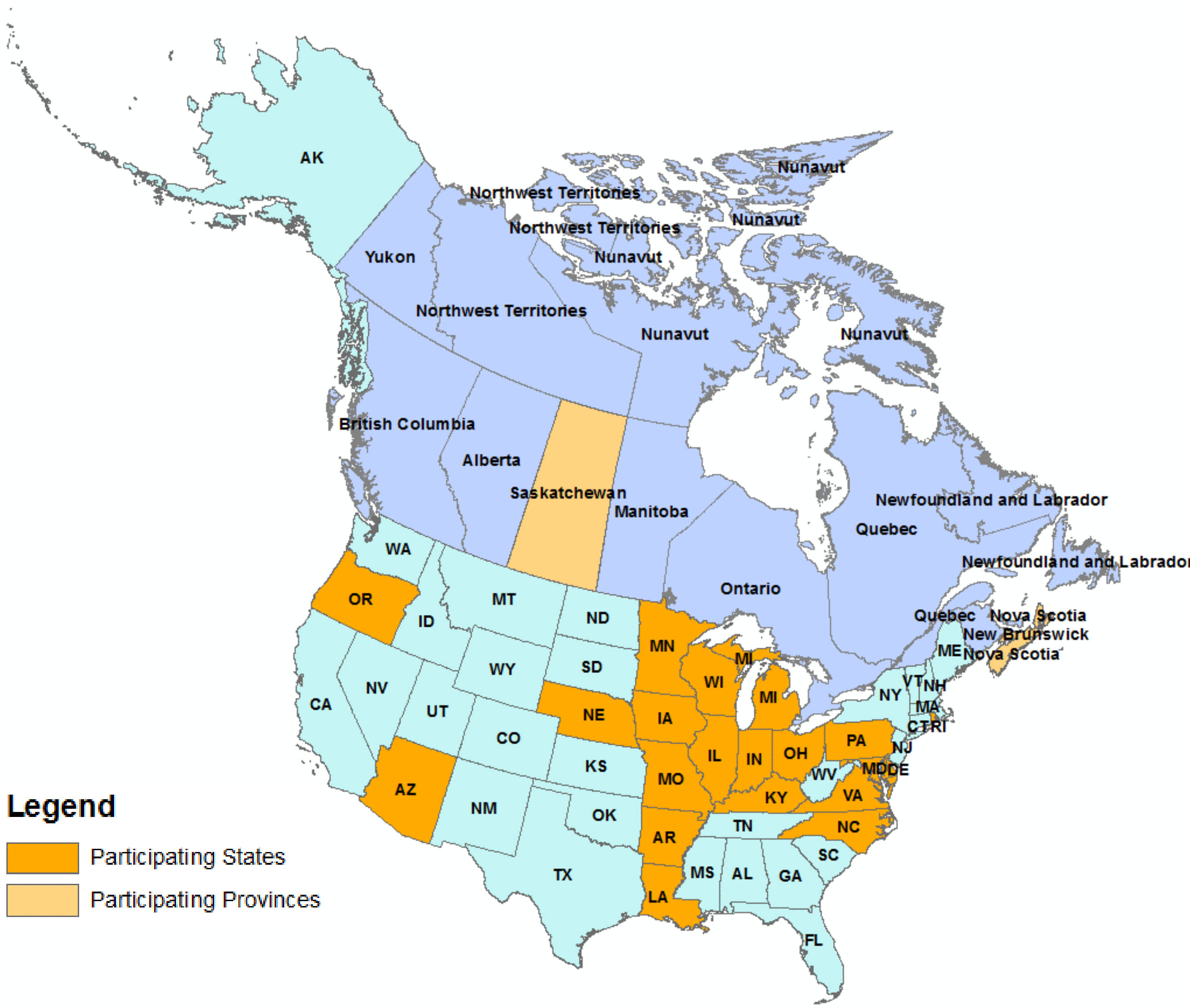



Figure 8: Participating states and provinces

#### 3.3.2.2 Delineator Systems

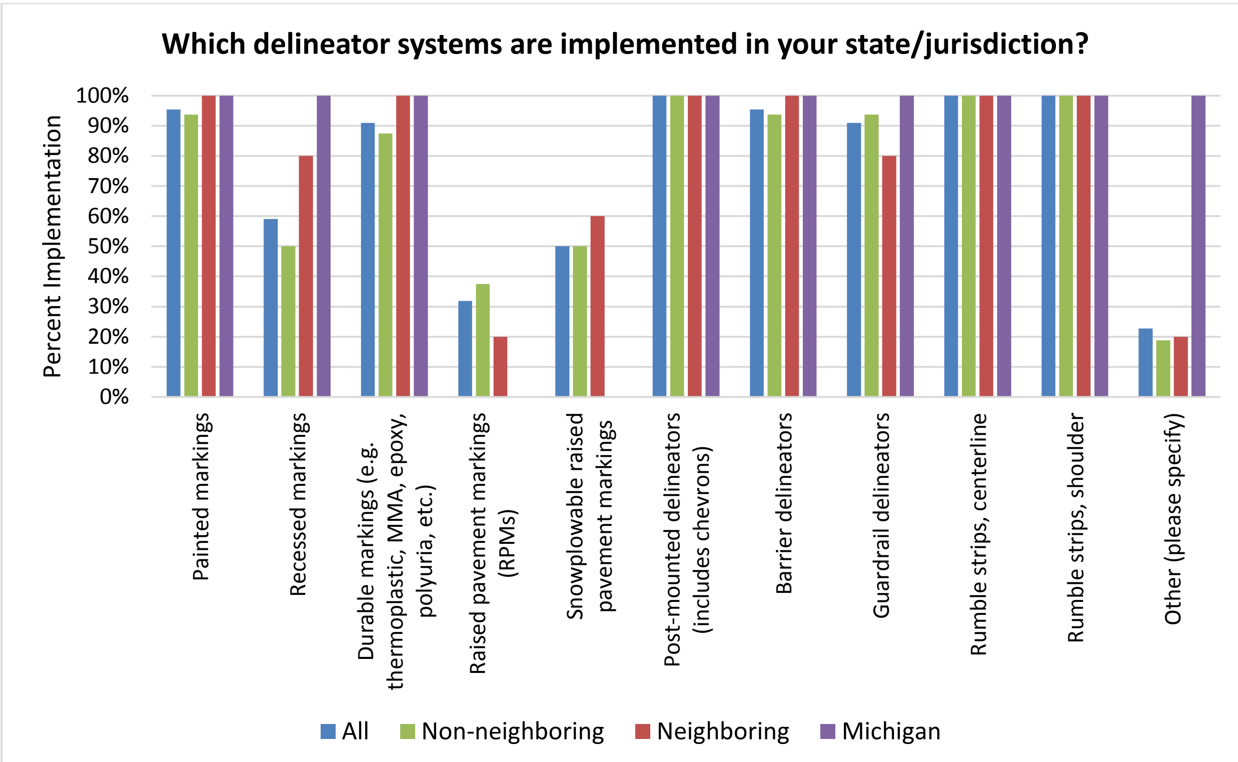



**Figure 9: Delineation system implementation**

Figure 9 shows the responses for the question regarding the implementation of delineation systems. 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), 1/10$^{th}$ 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 markers (RPMs), states are not using them due to snow plowing, and a few states may implement 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, cost, maintenance, and safety concerns (castings going through windshields).

#### 3.3.2.3 Painted Markings

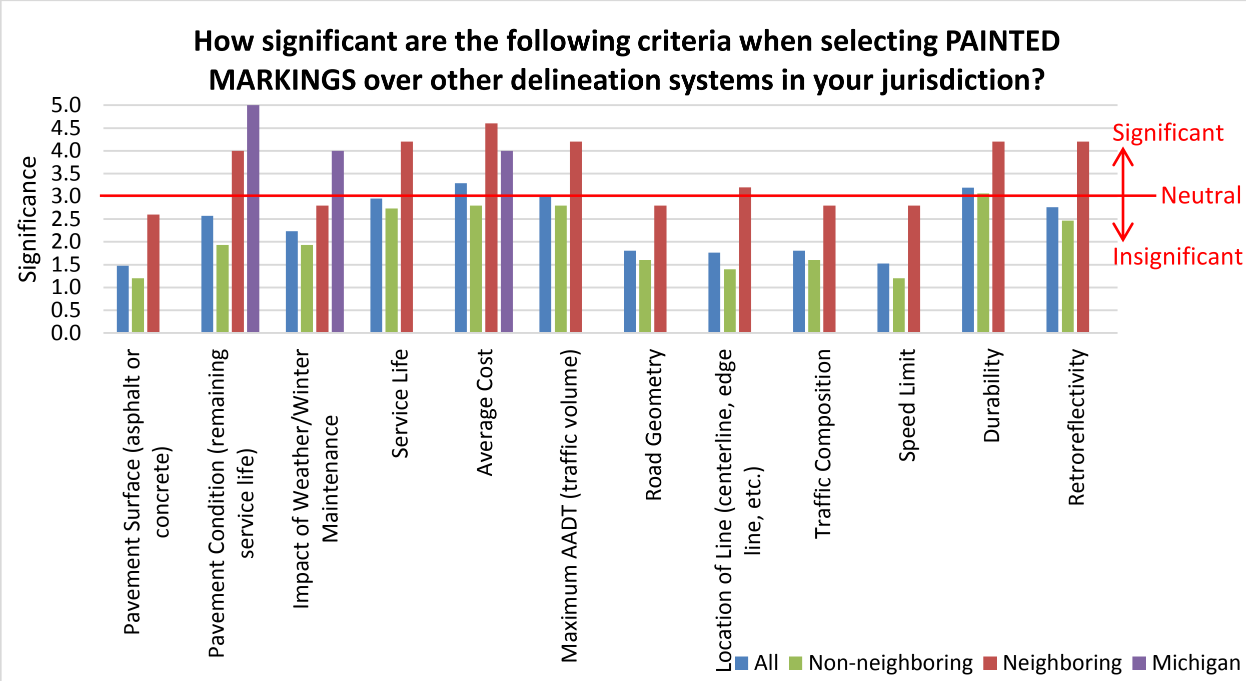



**Figure 10: Painted marking decision criteria**

In Figure 10, the decision criteria is shown for painted markings. For all questions regarding decision criteria, the responses are shown as a weighted average where significance is given the following values: zero (0) - Not Considered, one (1) - Very Insignificant, two (2) - Insignificant, three (3) - Neutral, four (4) - Significant, and five (5) - Very Significant. 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; and,
- 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; and,
- Often necessary to supplement with another form of delineation.

#### 3.3.2.4 Recessed Markings

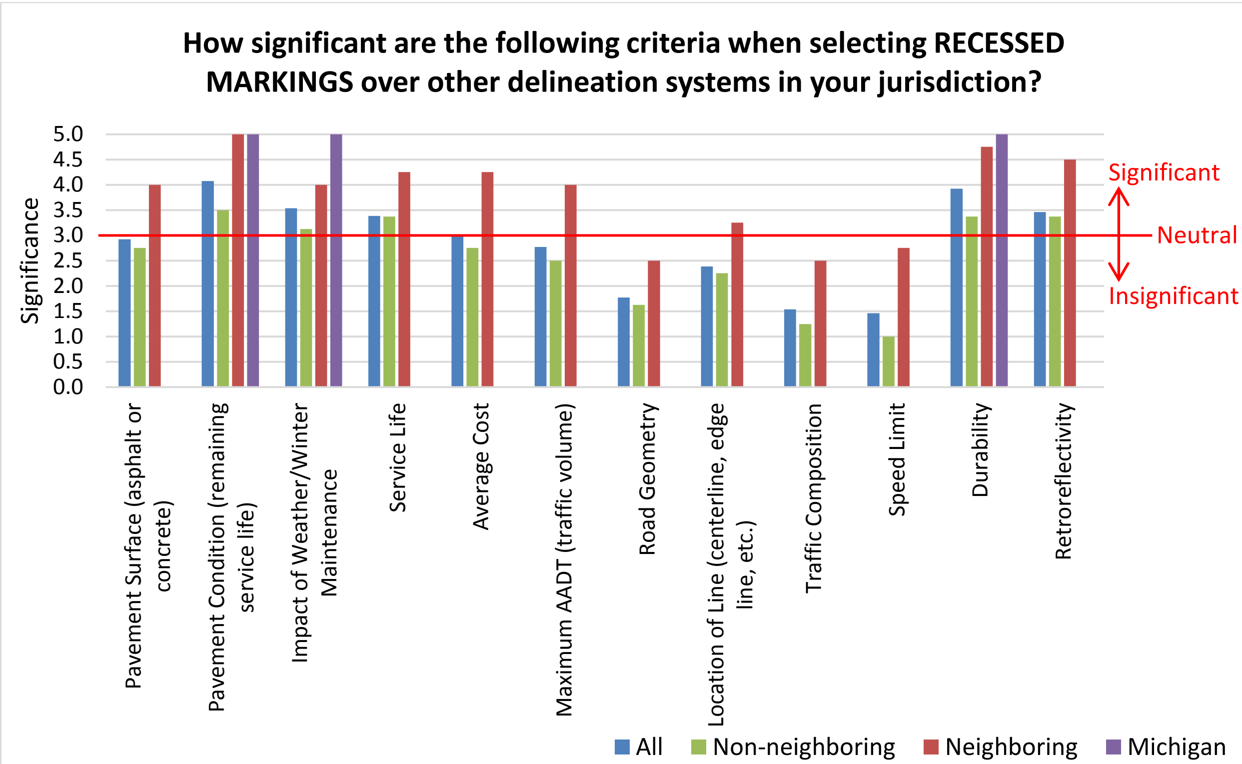



**Figure 11: Decision criteria for recessed markings**

In terms of recessed markings, Figure 11 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 were 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; and,
- 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; and,
- Recess must be clean before marking application.

#### 3.3.2.5 Durable Markings

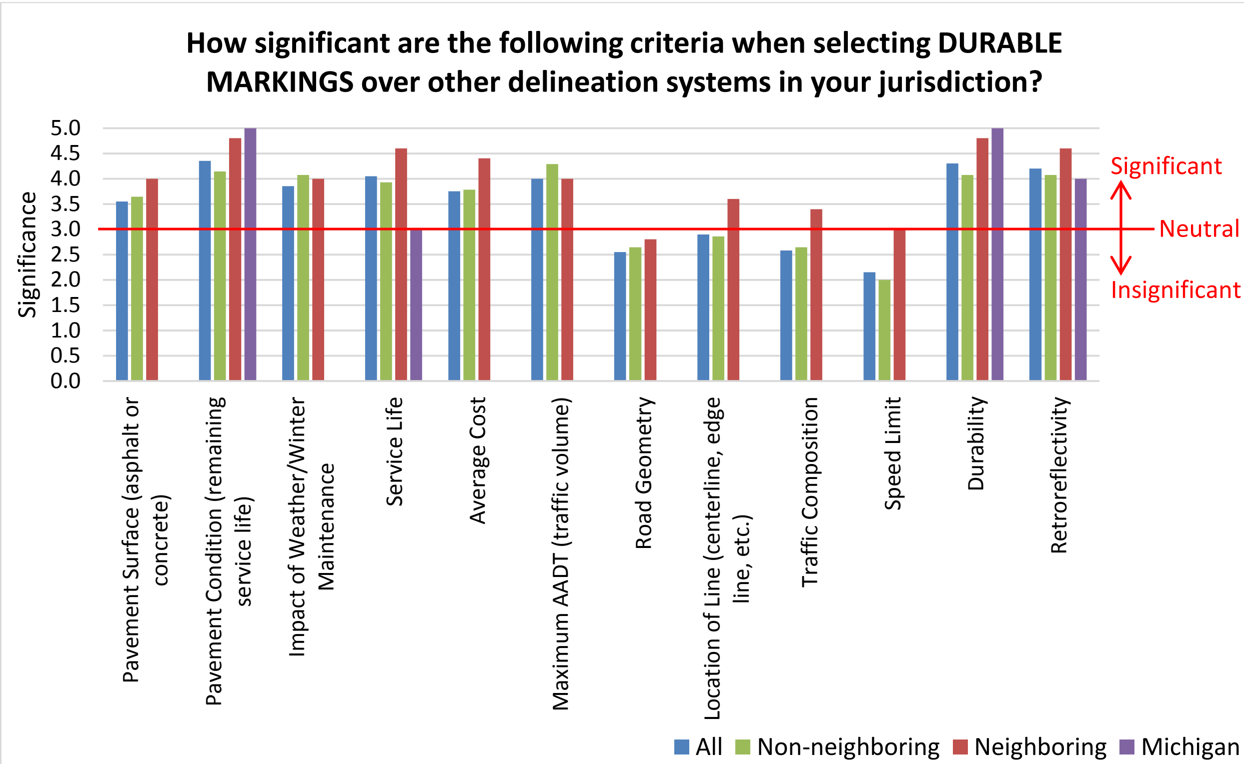



Figure 12: Decision criteria for durable markings

Figure 12 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.

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; and,
- 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; and,
- Easily incorrectly installed.

#### 3.3.2.6 Pavement Marking Materials

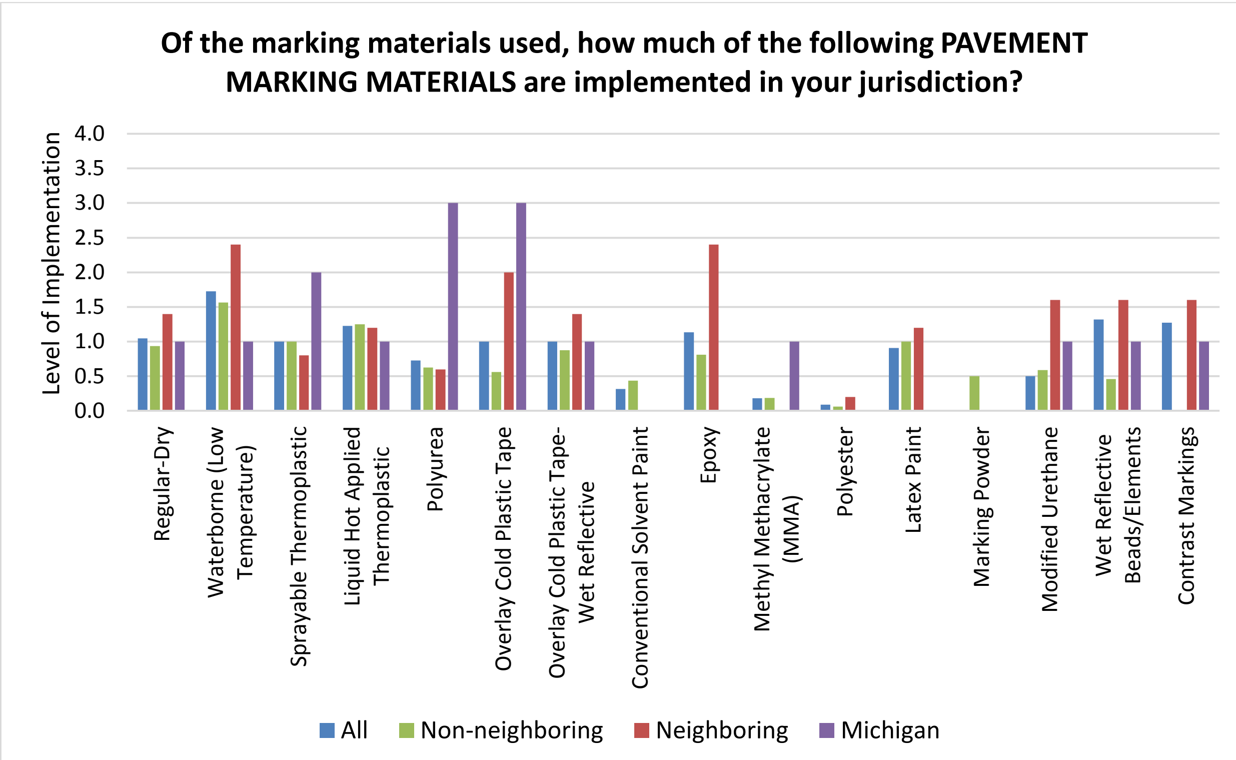



**Figure 13: Pavement marking materials by level of implementation**

Figure 13 depicts pavement marking materials by the amount that they are implemented. Of all marking materials implemented, the level of implementation is indicated by the following: zero (0) – None; 0%, one (1) - Very Little; <15%, two (2) – Little; 15-40%, three (3) – Some; 40-60%, four (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 one. 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 temp), hi-build paint, and low VOC (volatile organic compounds) acetone.

#### 3.3.2.7 Raised Pavement Markings

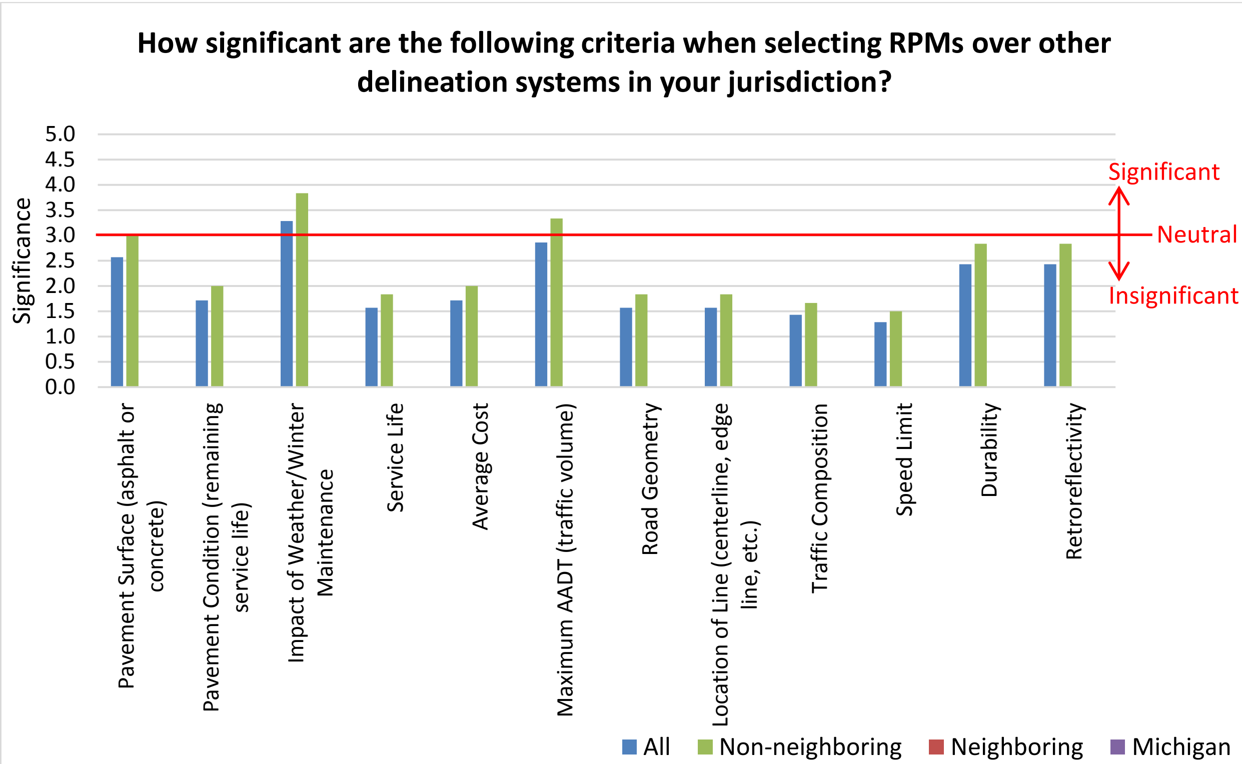



Figure 14: Decision criteria for raised pavement markings

In Figure 14, 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 significant.

Performance and effectiveness of RPMs were summarized as follows:

- Most effective wet-night performance;
- Liked by the public; and,
- Used in areas not snowplowed.

The followed issues are associated with RPMs:

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

#### 3.3.2.8 Snowplowable Raised Pavement Markings

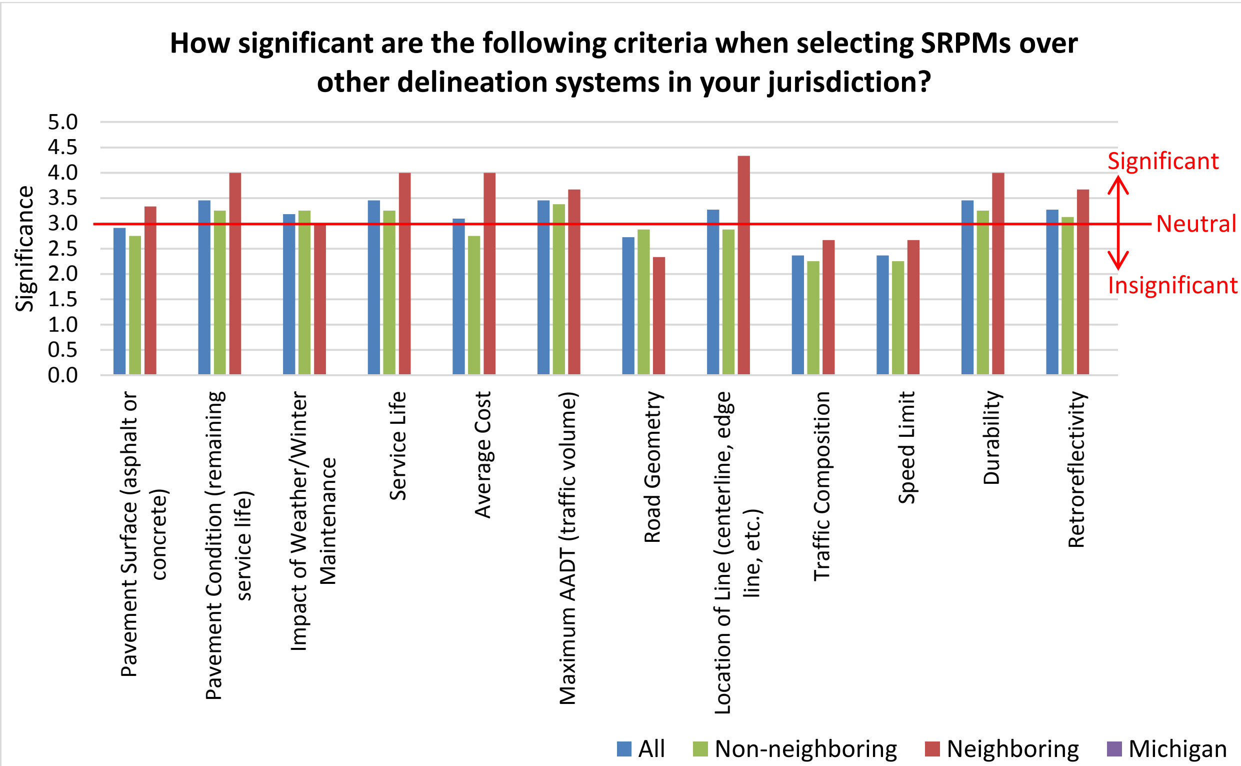



**Figure 15: Decision criteria for snowplowable raised pavement markings**

Figure 15 shows the decision criteria for snowplowable raised pavement markings (SRPMs). Overall, the most significant decision criteria were pavement condition, service life, maximum AADT, and durability. SRPMs are not implemented in Michigan. Another decision factor noted was quantity.

Performance and effectiveness were summarized as follows:

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

Issues that have been faced with SRPMs include:

- Casting may be dislodged and become a projectile by a passing vehicle and might hit or puncture a windshield;
- Reflectors may require frequent replacement; and,
- Snow plows remove metal casting as pavement ages.

#### 3.3.2.9 Post-Mounted Delineators

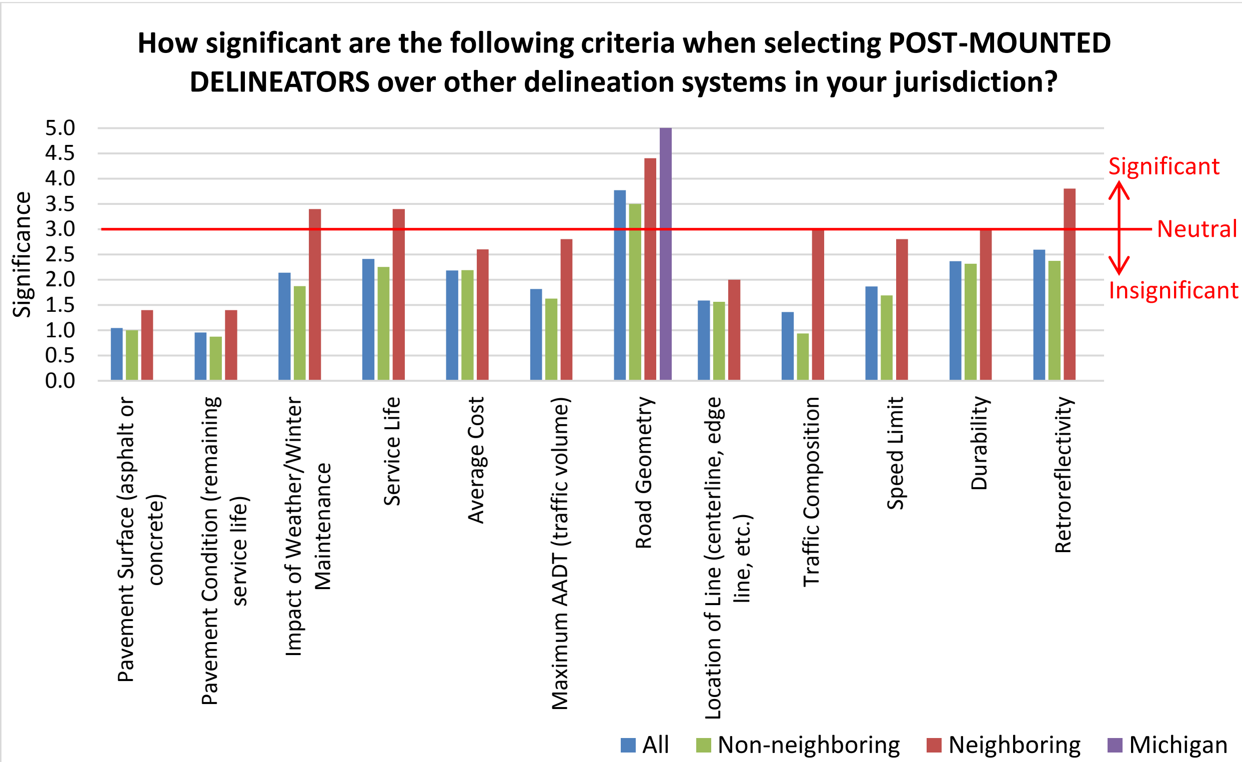


Figure 16: Decision criteria for post-mounted delineators

In Figure 16, 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 17 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 18 shows the distribution of the decision criteria for rigid and flexible delineators. Of all the responses, 26% indicated that the same criteria is used for both rigid and flexible delineators while 37% 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; and,
- 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; and,
- Poor reflective sheeting.

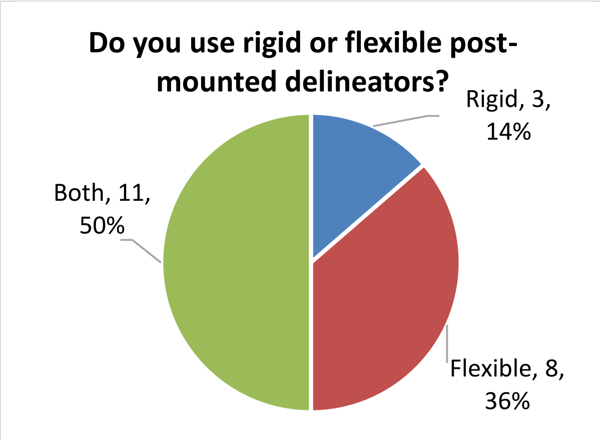



Figure 17: Use of rigid and flexible post-mounted delineators

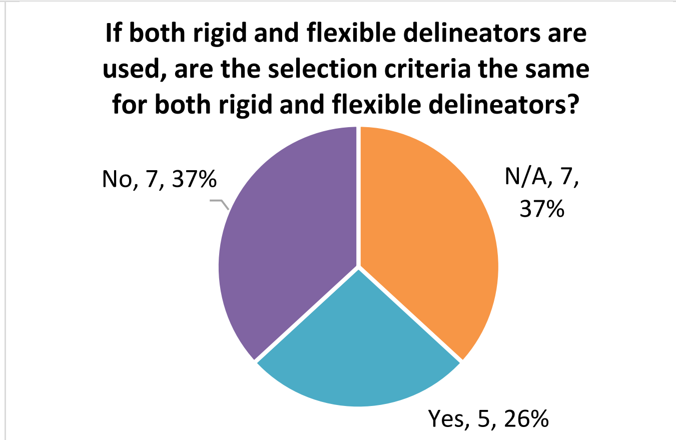



Figure 18: Decision criteria used for varying post types

#### 3.3.2.10 Barrier Delineators

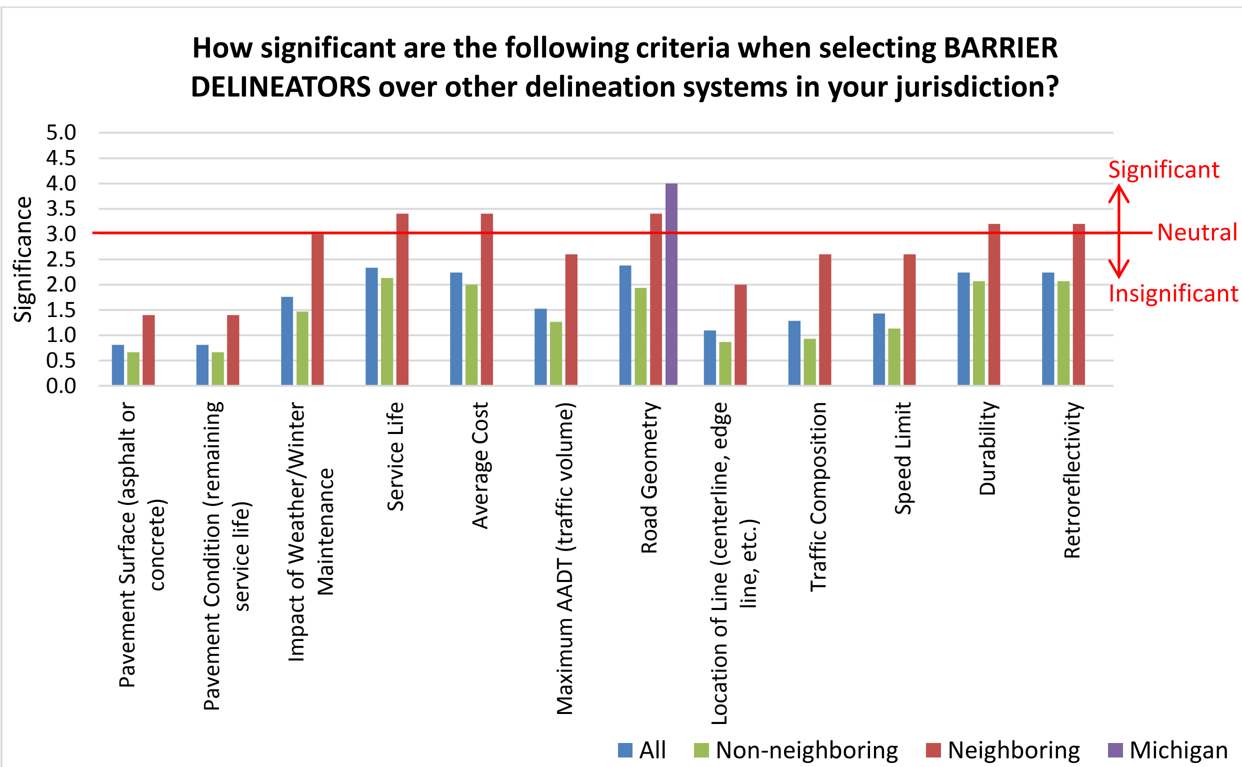



Figure 19: Decision criteria for barrier delineators

Figure 19 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.

The evaluation of performance and effectiveness of barrier delineators is as follows:

- Especially useful on ramps and horizontal curves; and,
- 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; and,
- Durability varies between providers.

#### 3.3.2.11 Guardrail Delineators

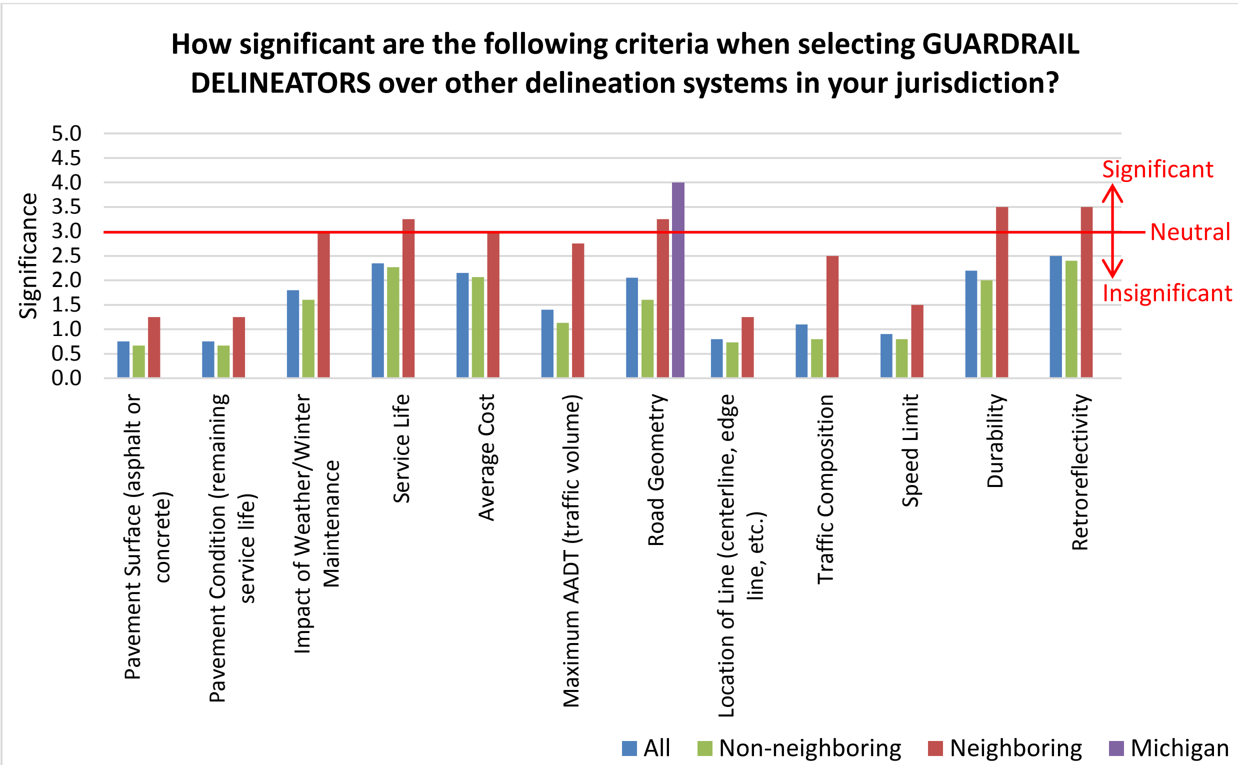



Figure 20: Decision criteria for guardrail delineators

In Figure 20, 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 considered is crash history.

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

- Effectiveness depends on installation height; and,
- 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; and,
- Damaged by snow removal.

#### 3.3.2.12 Centerline Rumble Strips

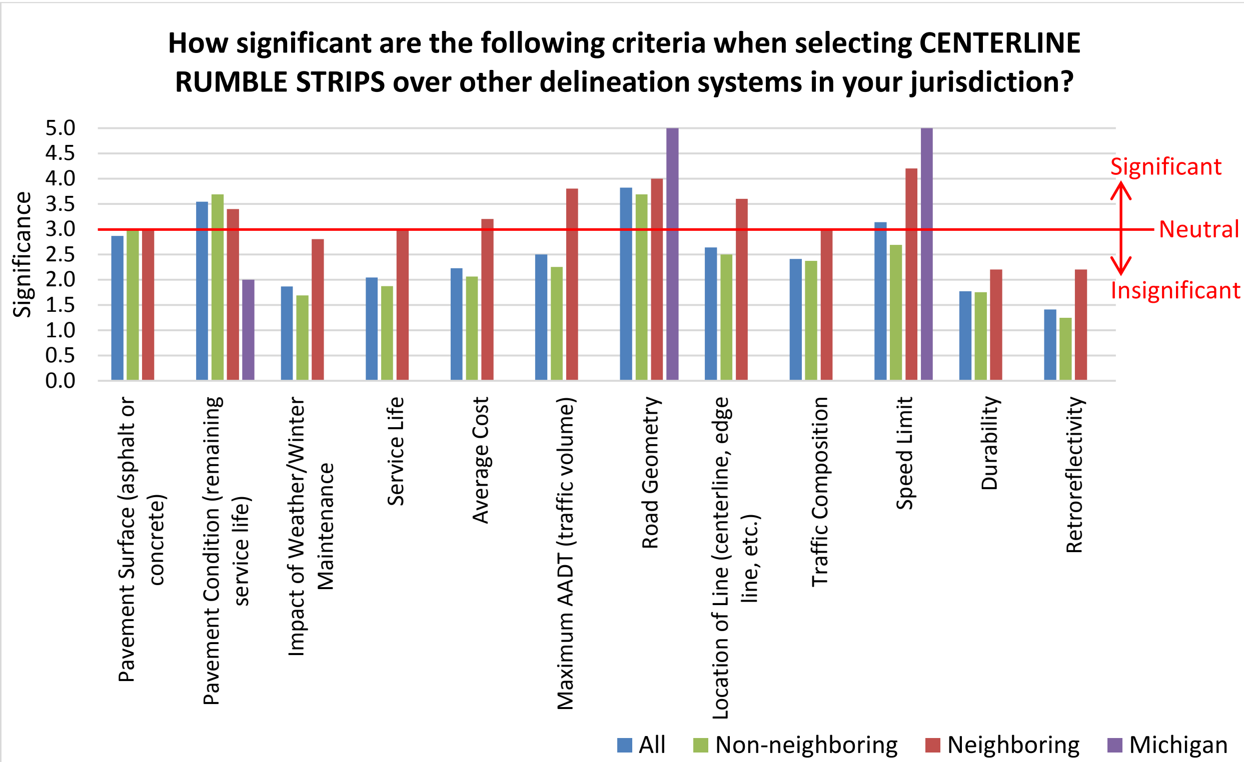



**Figure 21: Decision criteria for centerline rumble strips**

Figure 21 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 criteria, which 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; and,
- 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; and,
- Maintenance of rumble strips and markings.

#### 3.3.2.13 Shoulder Rumble Strips

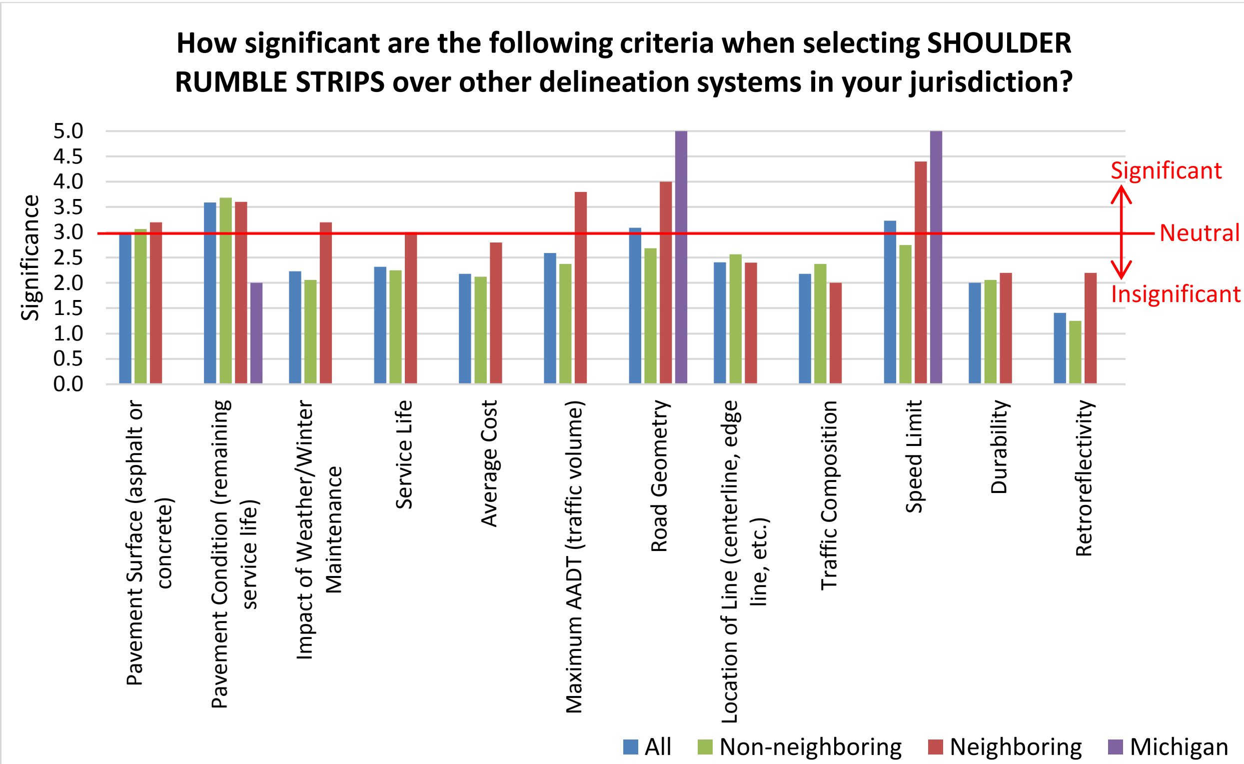



Figure 22: Decision criteria for shoulder rumble strips

In Figure 22, 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 are also 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; and,
- 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; and,
- Accommodating bicyclists.

#### 3.3.2.14 Life Span

Figure 23 shows the life span of the delineation systems considered. The minimum, average, and maximum were calculated. In general, painted markings have the shortest life span while rumble strips have the longest life span.

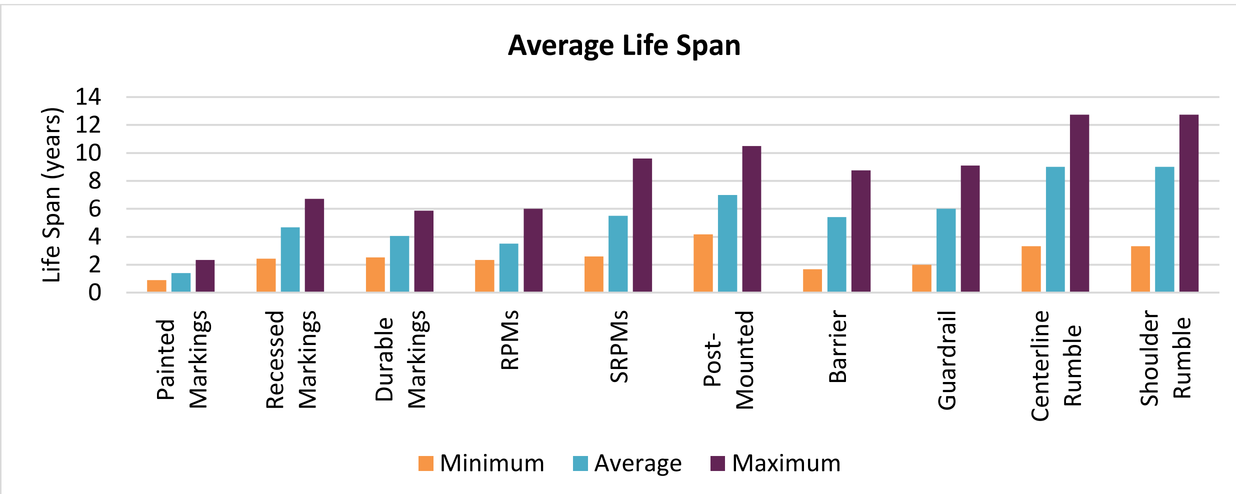



Figure 23: Average delineator life span in years

#### 3.3.2.15 Unit Cost

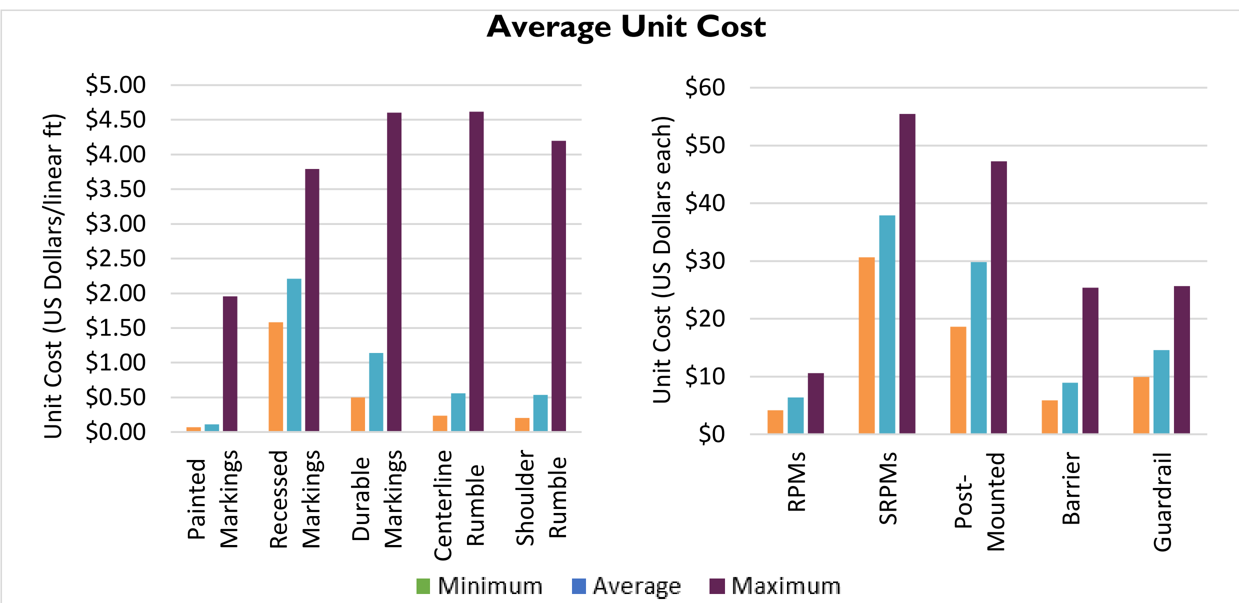



Figure 24: Average unit cost in US Dollars/linear foot (left) and US Dollars/each (right)

In Figure 24, the average unit cost for the delineation systems 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 are shown on the right. The least expensive delineation system is painted markings, while the most expensive is SRPMs.

#### 3.3.2.16 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 four or five, i.e. significant or very significant, respectively, were determined to be critical. Additionally, factors with an average significance between three and four were considered important.

Critical and important factors are summarized using these criteria in Tables 4 and 5. Critical factors are indicated with a "C" while important factors are denoted with an "I". Additionally, Michigan's responses are also indicated; one asterisk (*) indicates critical factors while two asterisks (**) indicates important factors. Any cells that are blank indicate an average significance that was less than three. In addition, Table 4 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 5.

In general, neighboring states seem to consider service life, average cost, durability, and retroreflectivity as the most significant factors in regard to 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 4: Critical factors as indicated by neighboring states**

| | Delineation System | Decision Criteria | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 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 |
| Neighboring | Painted markings | | I* | * | C | C* | C | | I | | | C | C |
| | Recessed markings | I | C* | I* | C | C | I | | I | | | C* | C |
| | Durable markings (e.g. thermoplastic, MMA, epoxy, polyurea, etc.) | I | C* | I | C** | C | I | | I | I | | C* | C* |
| | Raised pavement markers (RPMs) | | | | | | | | | | | | |
| | Snowplowable RPMs (SRPMs) | I | I | | I | I | I | | C | | | I | I |
| | Post-mounted delineators (includes chevrons) | | | I | I | | | C* | | | | I | |
| | Barrier delineators | | | | I | I | | I* | | | | I | I |
| | Guardrail delineators | | | | I | | | I* | | | | I | I |
| | Rumble strips, centerline | | I | | | I | I | I* | I | | C* | | |
| | Rumble strips, shoulders | I | I | I | | | I | I* | | | C* | | |

**Table 5: Critical factors as indicated by non-neighboring states**

| | Delineation System | Decision Criteria | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 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 |
| Non-neighboring | Painted markings | | * | * | | * | | | | | | I | |
| | Recessed markings | | I* | I* | I | | | | | | | I* | I |
| | Durable markings (e.g. thermoplastic, MMA, epoxy, polyurea, etc.) | I | C* | C | I** | I | C | | | | | C* | C* |
| | Raised pavement markers (RPMs) | I | | I | | | I | | | | | | |
| | Snowplowable RPMs (SRPMs) | I | | I | I | I | | | | | | I | I |
| | Post-mounted delineators (includes chevrons) | | | | | | | I* | | | | | |
| | Barrier delineators | | | | | | | * | | | | | |
| | Guardrail delineators | | | | | | | * | | | | | |
| | Rumble strips, centerline | I | I | | | | | I* | | | * | | |
| | Rumble strips, shoulders | I | I | | | | | * | | | * | | |

## 3.4 Statistical Analysis

The research team developed crash modification factors (CMFs) where possible and utilized the CMFs documented in the FHWA's CMF Clearinghouse to estimate crash reductions associated with additional specific delineation systems. These CMFs were applied to selected sites and combined with the length in order to predict the reduction in crashes per mile for any given delineation treatment. Annual crash savings due to a reduction in crashes was then computed. The present value of these benefits were calculated in addition to the present value of the treatment costs to develop the benefit-cost ratio.

# 4 Data Collection

The data collection process consisted of reviewing documents that are referenced in MDOT's existing delineation program for clarity and to identify potential opportunities for improvements. These documents include guidelines, standard specifications, and special provisions. Inventories of existing data and GIS information were also gathered and reviewed for a variety of delineation assets. This data was used to estimate costs related to upgrading/replacing delineation components. Gaps that have been identified during the research team's review of documents and data inventories are noted in the following sections. A variety of delineation treatments were also reviewed in the field on Michigan roads. Limited field reviews also took place in the neighboring states of Ohio and Wisconsin.

### 4.1.1 Trialed Delineators

Various reflectors that have been recently trialed in Michigan were presented by MDOT's pavement marking and delineation unit along with subjective thoughts about their performance. Figure 25 shows the various delineation products under natural lighting conditions (indoors, fluorescent lighting) while Figure 26 shows the same products illuminated by a camera's flash (which is analogous to the lighting provided by a vehicle's headlights at night). Each delineation treatment shown in Figure 25 is numbered and associated with the details listed below.

Concrete barrier/guardrail delineators:

1. snaps due to windy conditions (mounted on top of barrier)

2. is currently being used (mounted on top of barrier)

3. currently under trial (mounted on top of barrier)

4. barrier side mount

5. bi-directional channel. Field applications of this are shown in following sections.

Guardrail only delineators:

6. bi-directional installation

7. can be used as an option

8. more flexible than 7

9. fiberglass, not preferred

10. consists of a urethane hinge, currently under trial

Post-mounted delineators:

11. button reflector

12. 3x6 sheeting, recently trialed, shatter resistant, preferred. Expanded use of this sheeting has been installed in North and Superior Regions.

Field installations of some of these products are shown in Section 4.1.2 Field Reviews.

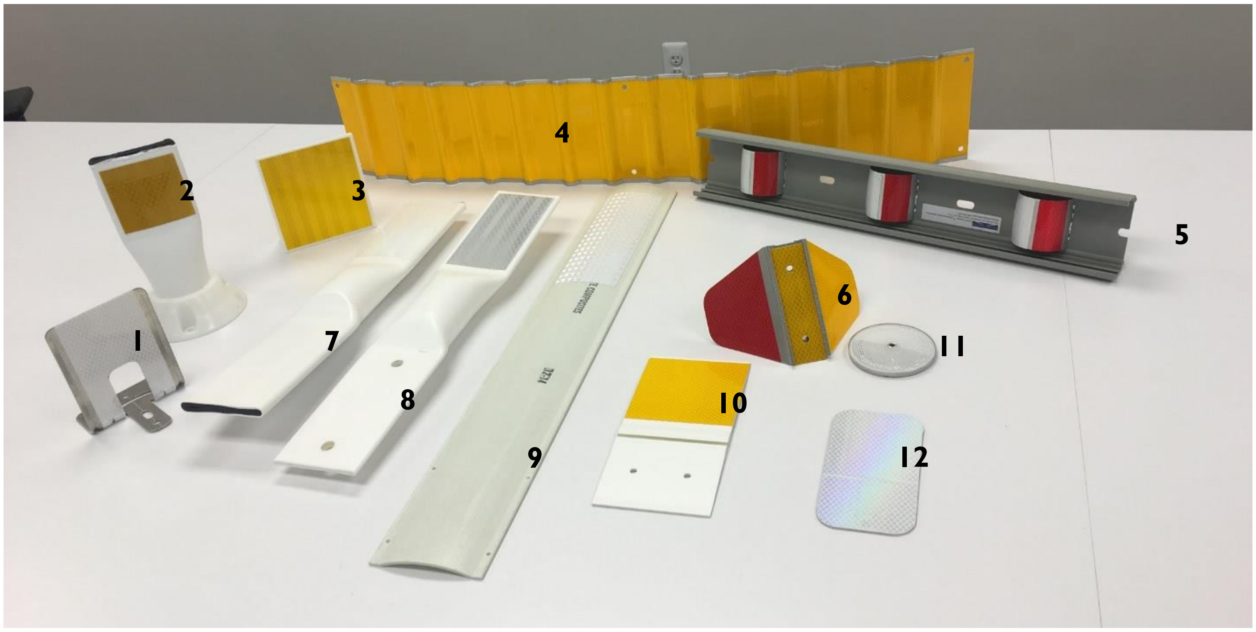



Figure 25: Trialed delineators under natural lighting

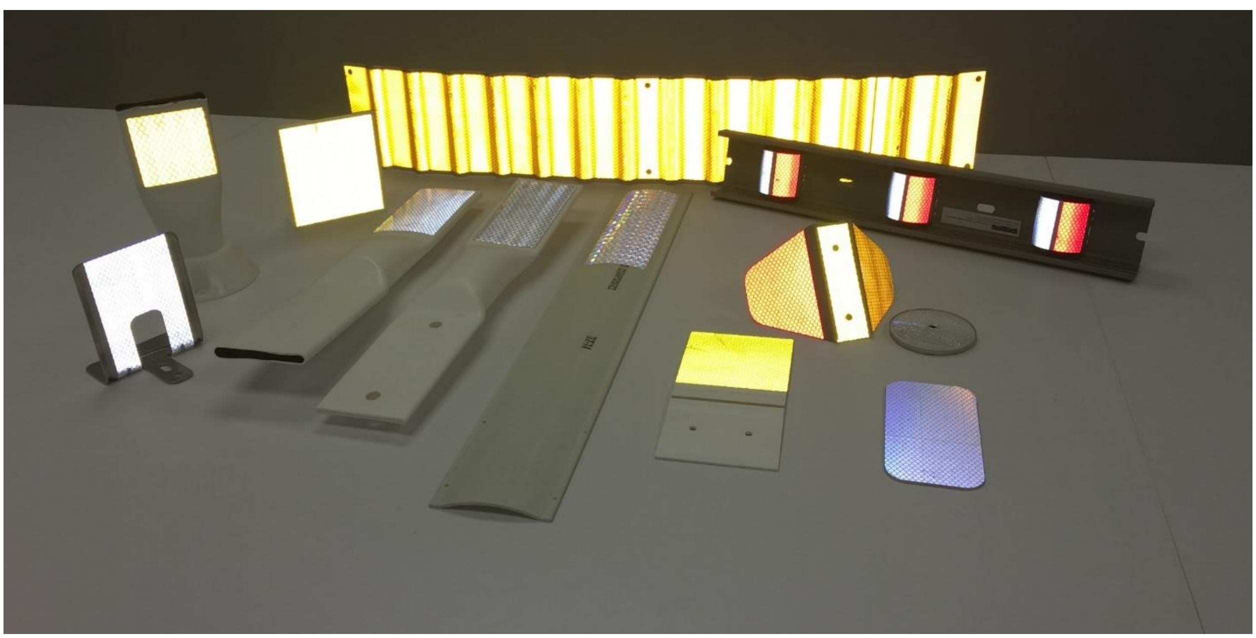


Figure 26: Trialed delineators showing various levels of retroreflectivity

### 4.1.2 Field Reviews

Field reviews were performed in Michigan and the neighboring states of Ohio and Wisconsin. In Michigan, experimental special markings (e.g. crosswalks and stop bars), green painted bike lanes, long line markings, and reflectors were visited and reviewed in the field. In Ohio and Wisconsin different types of contrast markings were reviewed. Additional treatments in Ohio were reviewed including rumblestrips and snowplowable raised pavement markers.

#### 4.1.2.1 Michigan

Various delineation products have been installed to enhance the driving experience in Michigan. While experimental special markings (e.g. crosswalks and stop bars) were visited, only long line markings and reflectors are shown in this section.


Figure 27: 3M LDS barrier side mount reflectors on EB I-94, west of I-94BL, Kalamazoo, Michigan (Image courtesy of Google Street View)

**Figure 28: Luciol Systems Bi-directional reflector installed in guardrail channel (Image courtesy of Google Street View)**

**Figure 29: Damaged Luciol Systems Bi-directional reflector installed on barrier wall (Photo taken June 13, 2016. Opus International Consultants Inc.)**

The Luciol reflectors may be installed in the channel of guardrail as shown along EB M-14 south of Barton Drive (Figure 28) or on the face of barrier wall as shown along the SB Mound Road to EB I-696 Ramp (Figure 29).

Figure 30: HPS-8 installation on Eton Road in Birmingham, Michigan (Photo taken June 13, 2016. Opus International Consultants Inc.)

HPS-8 is a multipolymer product, which is holding up well where the surface was prepared properly (e.g. grinding debris is removed from the recess and proper temperature controls are followed). As shown in Figure 30, the glass beads are still visible after more than one year of traffic and snow removal operations.

**Figure 31: Profiled (splatter) Methyl Methacrylate edge line, from side and top**

Methyl Methacrylate (MMA) has been installed on NB US-24 between Lone Pine and Long Lake Roads, in Bloomfield Hills, Michigan (see Figure 31). This installation has been holding up well under heavy traffic (~37,000 ADT) and snow removal operations. The texture enhances the retroreflectivity as there are multiple surfaces (and therefore angles) to reflect light.


**Figure 32: Contrast markings on SB I-275**


Figure 33: Contrast markings on NB I-69 (Image Courtesy of Google Street View)

Contrast markings have been installed on new concrete pavements, including I-96 east of I-275 and more recently on I-275 between M-14 and I-696. These black markings, as shown in Figure 32, enhance the contrast of pavement markings on light colored pavement. In Figure 33, older contrast markings are still visible along NB I-69 near Charlotte, Michigan (the black paint is epoxy, which is still visible after more than ten years).

Figure 34: Bordered contrast markings on WB US-10

On WB US-10, east of Coleman, in Midland County, Michigan, bordered contrast markings have been installed.

Figure 35: Reflective sign sheeting as delineators

Reflective sign sheeting has been used in place of buttons and flexible delineators. These photos are examples of delineators installed in MDOT's North Region.

#### 4.1.2.2 Ohio

Contrast markings in neighboring states were sought for comparison to Michigan. In Figure 36, shadowed contrast markings are visible on SB I-280 near Toledo, Ohio. Overhead lighting is also present on this section of freeway.

Figure 36: Contrast markings on SB I-280

Certain freeways in Ohio also use other treatments found in Michigan such as center and edgeline rumble strips, as well as treatments that are not currently implemented by MDOT, such as snowplowable raised pavement markers (SRPMs), as seen in Figure 36 on SB I-280 near Toledo, Ohio, and in Figure 37 along EB I-80. SB I-280 also has overhead lighting, hence the lack of reflectors on the guardrail. I-80 does not have overhead lighting along rural stretches of the turnpike, but post-mounted reflectors are present outside the shoulder.


Figure 37: Rumblestrips and SRPMs on SB I-280

Figure 38: Rumblestrips and SRPMs on EB I-80

#### 4.1.2.3 Wisconsin

Wisconsin has also implemented bordered contrast markings. On NB US-51, near Wausau, they have used borders to enhance the contrast of both lane lines and gore markings.


Figure 39: Bordered contrast markings on NB US-51

Figure 40: Bordered contrast markings on NB US-51

# 5 Cost Benefit Analysis

## 5.1 Development of Crash Modification Factors

### 5.1.1 Site Selection

In order to complete the statistical crash analysis, it was necessary to select a representative group of delineated roadway sites on which to perform the necessary calculations. The results of the statistical crash analysis were used to develop crash modification factors which were used to calculate the benefit-cost. 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 site 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 proportional distribution among the parameters.

One challenge with this analysis was compiling complete sets of data. Guardrail location data was obtained through MDOT. However, two regions (Five and Six) were not included in the guardrail inventory due to missing information. Therefore, no sites were selected from these regions.

### 5.1.2 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 analysis was accomplished through the use of 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:

$$CMF_i = \exp(C_i V) \quad (1)$$

*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:

$$CRF = 1 - CMF \quad (2)$$

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 *(60)*.

### 5.1.3 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.

### 5.1.4 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.

#### 5.1.4.1 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 41 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 42 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.

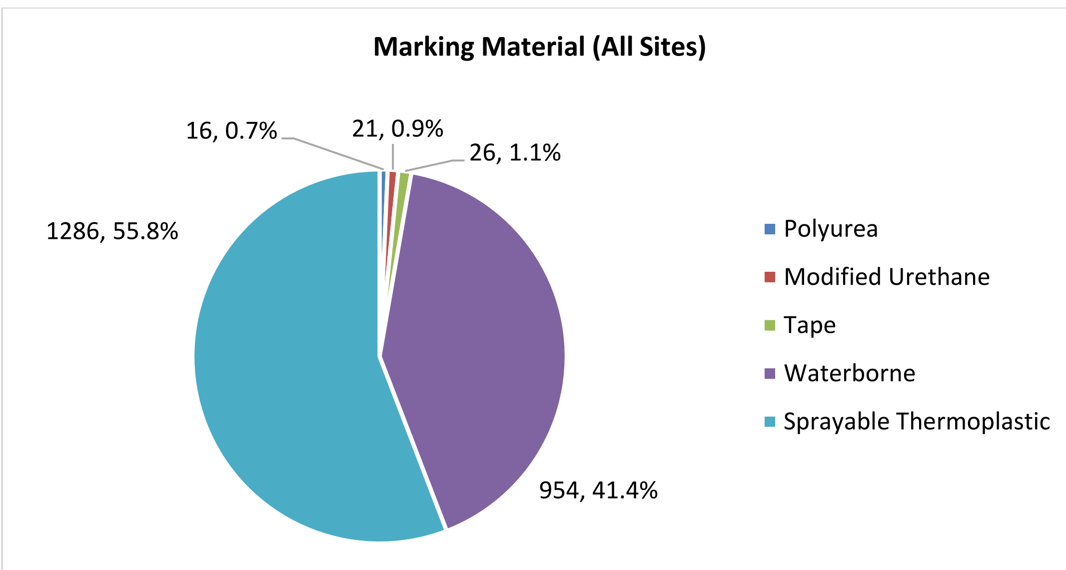



Figure 41: Distribution of marking material implementation for all sites

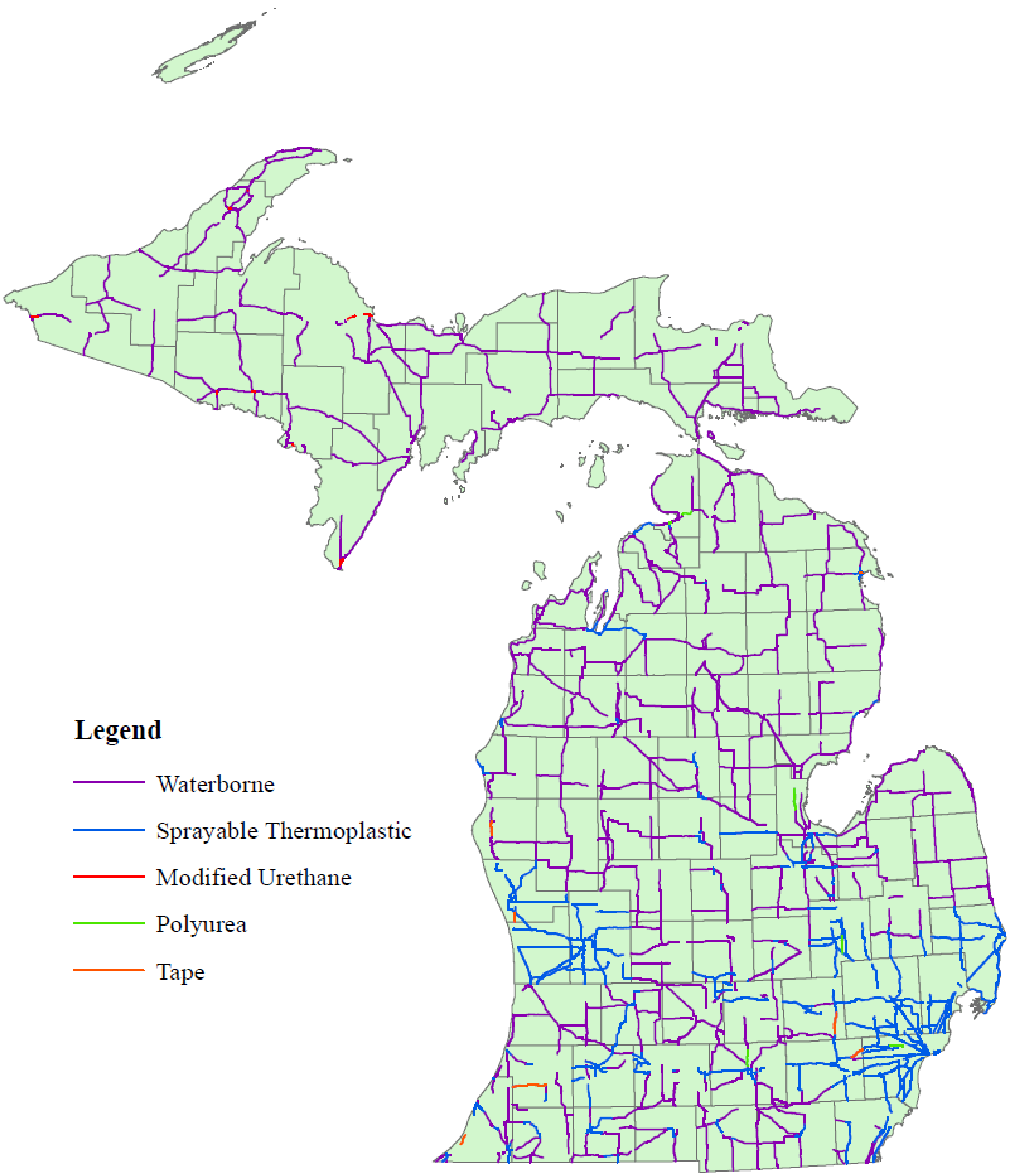



Figure 42: All sites in marking material inventory based on marking material

#### 5.1.4.2 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 Five and Six 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 44 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 43. Sites are shown in different colors that correspond with the implemented material.

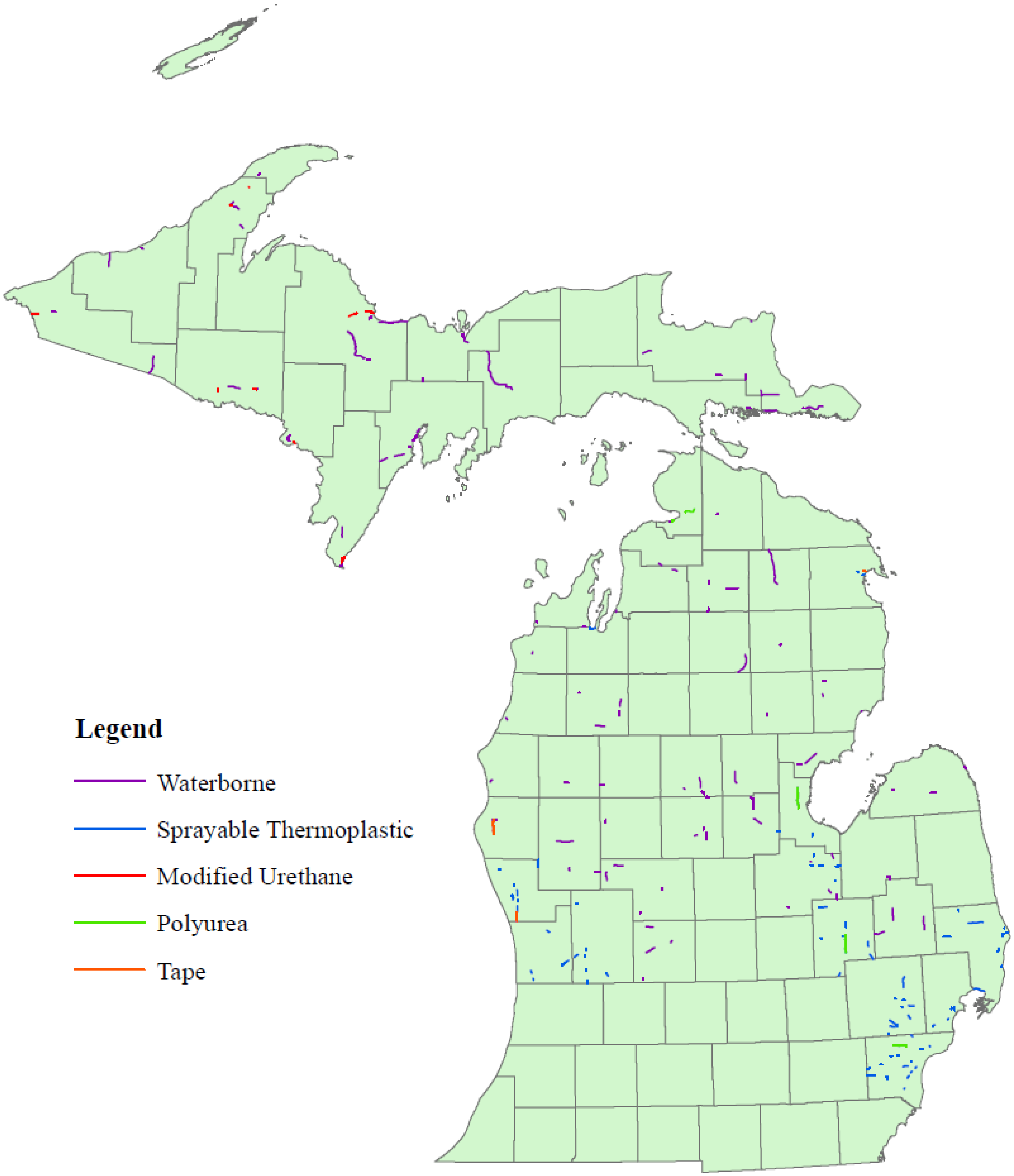


Figure 43: Selected sites from marking material inventory based on marking material

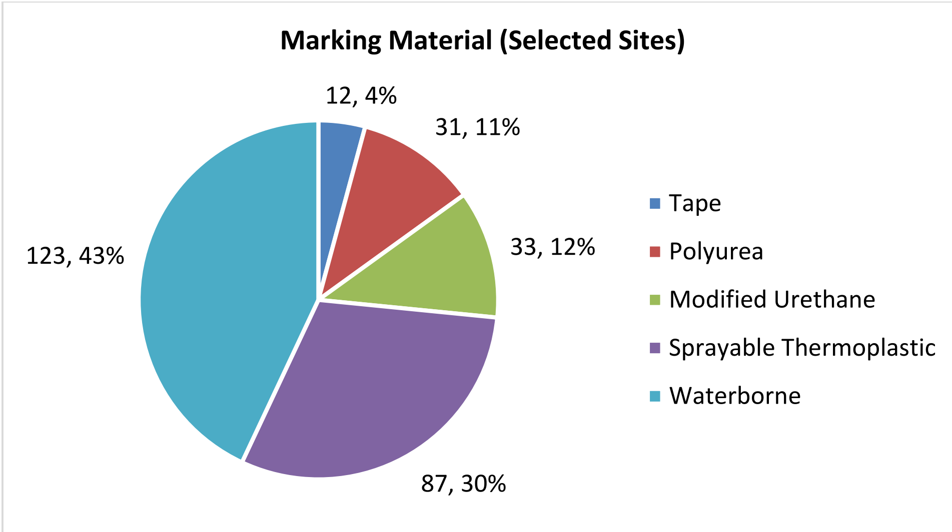



**Figure 44: Distribution of marking materials among selected sites**

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 45 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.

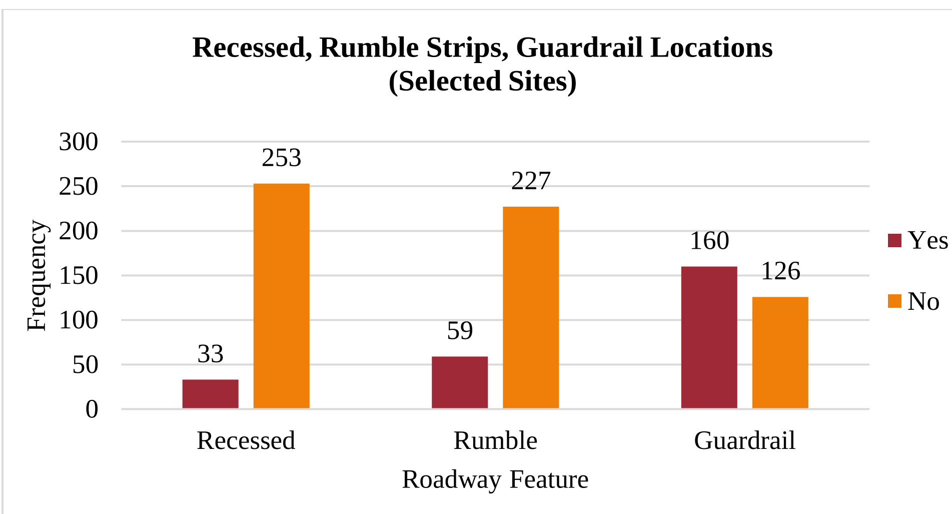



**Figure 45: Frequency of recessed, rumble strip, and guardrail locations within the selected sites**

### 5.1.5 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.

#### 5.1.5.1 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 46 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.

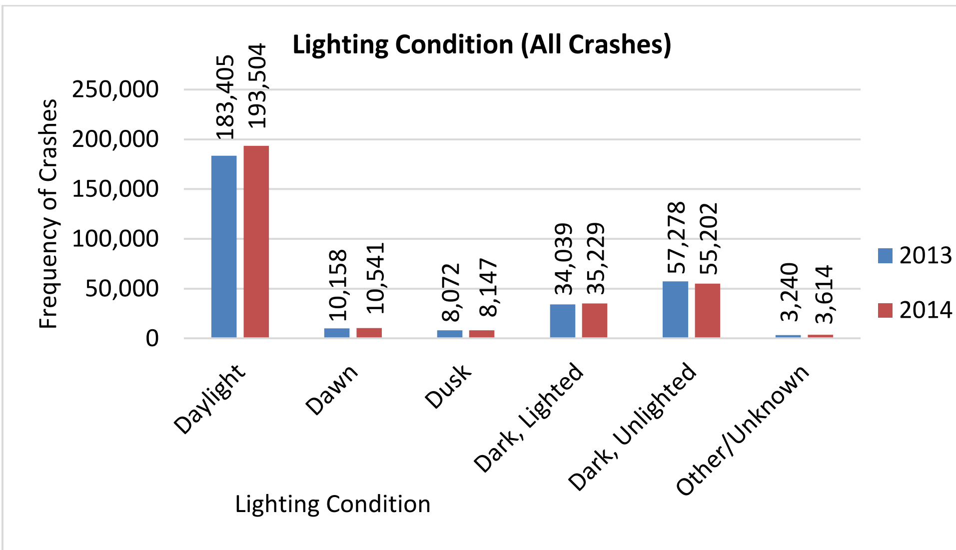



Figure 46: Frequency of total crashes by lighting condition and year

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 47 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.

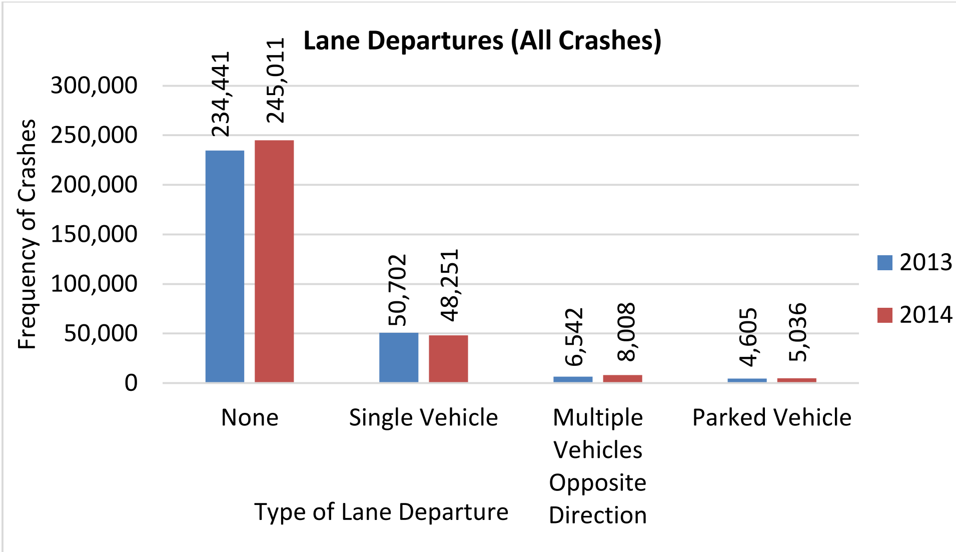



Figure 47: Frequency of all crashes by lane departure and year

Figure 48 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 47. 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.

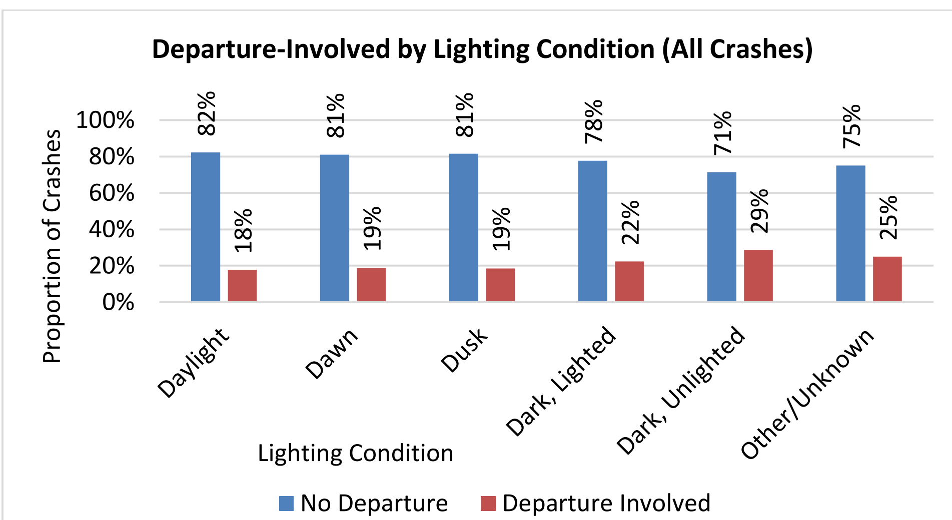



Figure 48: Proportion of departure-involved crashes by lighting condition for all crashes (2013-2014)

#### 5.1.5.2 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 and 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.

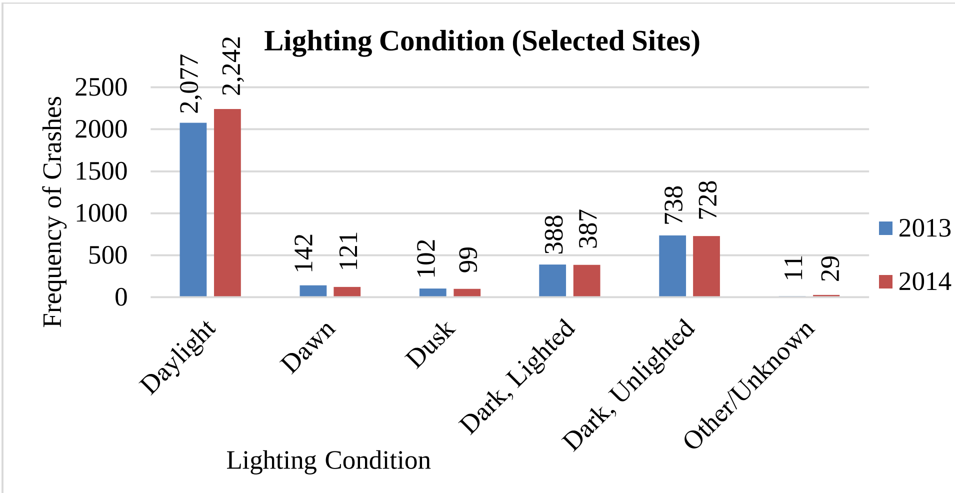



Figure 49: Frequency of crashes in selected sites by lighting condition and year

The distribution of crashes for the selected sites in regard to lighting condition is shown in Figure 49. 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 50 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.

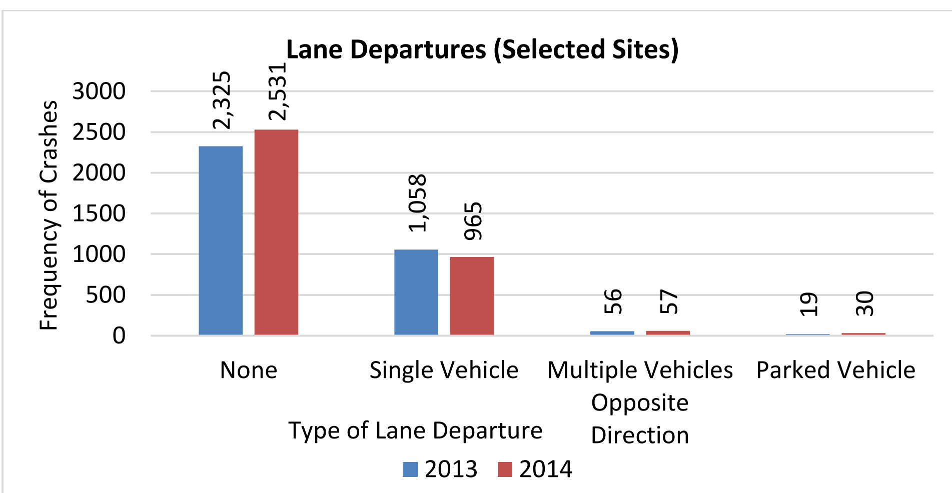



Figure 50: Frequency of crashes in selected sites by lane departure and year

In Figure 51, 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.

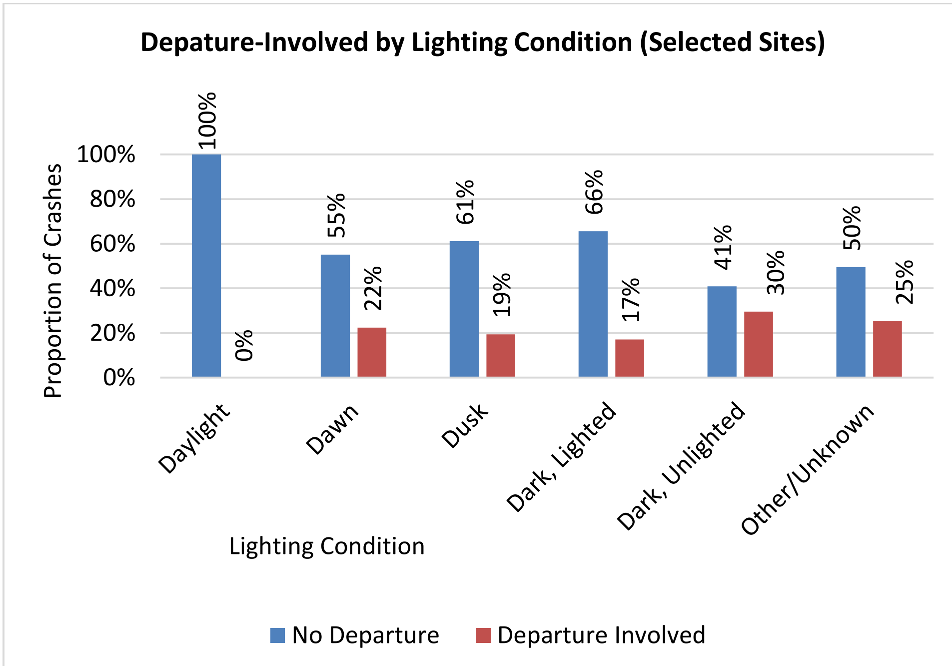



Figure 51: Proportion of departure-involved crashes by lighting condition for selected sites (2013-2014)

### 5.1.6 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 6 details the variables that were utilized in the modeling analysis. The variable names are listed followed by a description and descriptive statistics.

**Table 6: Variables tested through statistical modeling**

| Variable | Description | Mean | Std Dev* | Min | Max |
|---|---|---|---|---|---|
| wtbn | Indicates implementation of waterborne paint | 0.430 | 0.496 | 0 | 1 |
| stp | Indicates implementation of sprayable thermoplastic | 0.304 | 0.461 | 0 | 1 |
| tape | Indicates implementation of cold or wet tape | 0.042 | 0.201 | 0 | 1 |
| poly | Indicates implementation of polyurea | 0.108 | 0.311 | 0 | 1 |
| mu | Indicates implementation of modified urethane | 0.115 | 0.320 | 0 | 1 |
| nfc_1 | National Functional Class (NFC) indicator for arterials | 0.969 | 0.175 | 0 | 1 |
| nfc_2 | National Functional Class (NFC) indicator for collectors | 0.000 | 0.000 | 0 | 0 |
| pop_1 | Population group indicator, rural, less than 5,000 | 0.657 | 0.475 | 0 | 1 |
| pop_2 | Population group indicator, urban, greater than 5,000 | 0.343 | 0.475 | 0 | 1 |
| surf_1 | Surface type indicator, flexible | 0.360 | 0.481 | 0 | 1 |
| surf_2 | Surface type indicator, rigid | 0.238 | 0.426 | 0 | 1 |
| surf_3 | Surface type indicator, composite | 0.402 | 0.491 | 0 | 1 |
| length | Length of the segment, miles | 1.630 | 2.253 | 0.055 | 21.74 |
| surf_width | Width of the pavement surface, feet | 32.50 | 13.32 | 16 | 86 |
| num_lanes | Number of through lanes | 2.552 | 0.945 | 1 | 6 |
| lane_width | Width of through traffic lanes, feet | 11.78 | 0.513 | 10 | 16 |
| pass_lane | Indicates presence of passing lane | 0.024 | 0.155 | 0 | 1 |
| median_wid | Width of median for divided segments | 24.90 | 48.12 | 0 | 550 |
| spd_limit | Posted speed limit, miles per hour | 52.75 | 14.05 | 25 | 70 |
| pct_rstr | Percent of no-passing zone for the length of the segment | 10.54 | 23.802 | 0 | 100 |
| r_shdr_wid | Right shoulder width, feet | 6.972 | 4.270 | 0 | 14 |
| r_shdr_pvd | Width of paved right shoulder, feet | 5.353 | 3.984 | 0 | 12 |
| l_shdr_wid | Left shoulder width, feet | 3.126 | 4.099 | 0 | 12 |
| l_shdr_pvd | Width of paved left shoulder, feet | 2.224 | 3.220 | 0 | 12 |
| non_motor | Indicates presence of non-motorized facilities | 0.070 | 0.255 | 0 | 1 |
| aadt_1000 | Annual Average Daily Traffic, thousands | 14.99 | 16.93 | 0.471 | 79.9 |

| Variable | Description | Mean | Std Dev* | Min | Max |
|---|---|---|---|---|---|
| pct_comm | Percentage of traffic made up of commercial vehicles | 5.248 | 3.803 | 1 | 32 |
| signal_int | Indicates presence of one or more signalized intersections | 0.311 | 0.464 | 0 | 1 |
| gores | Indicates number of gores present | 0.035 | 0.311 | 0 | 4 |
| recess | Indicates presence of recessed markings | 0.115 | 0.320 | 0 | 1 |
| rumble | Indicates presence of rumble strips | 0.206 | 0.405 | 0 | 1 |
| guardrail | Indicates presence of guardrails | 0.559 | 0.497 | 0 | 1 |
| total_13_14 | Total crashes for the segment, 2013-2014 | 26.68 | 27.86 | 1 | 164 |
| lit_night_13_14 | Total crashes occurring at night, 2013-2014 | 7.850 | 7.911 | 0 | 44 |
| dprt_any_13_14 | Total crashes involving a vehicle road departure, 2013-2014 | 5.986 | 8.676 | 0 | 74 |
| region_1 | Indicates location in Region 1 | 0.318 | 0.467 | 0 | 1 |
| region_2 | Indicates location in Region 2 | 0.133 | 0.340 | 0 | 1 |
| region_3 | Indicates location in Region 3 | 0.157 | 0.365 | 0 | 1 |
| region_4 | Indicates location in Region 4 | 0.206 | 0.405 | 0 | 1 |
| region_7 | Indicates location in Region 7 | 0.185 | 0.389 | 0 | 1 |
| terrain_level | Indicates areas with level terrain | 0.850 | 0.358 | 0 | 1 |
| terrain_rolling | Indicates areas with rolling terrain | 0.150 | 0.358 | 0 | 1 |
| median_typ_none | Indicates an undivided roadway | 0.577 | 0.495 | 0 | 1 |
| median_typ_concrete | Indicates roadway with a concrete median barrier | 0.108 | 0.311 | 0 | 1 |
| median_typ_guard | Indicates roadway with a guardrail in the median | 0.014 | 0.118 | 0 | 1 |
| median_typ_ditch | Indicates roadway with a ditch in the median | 0.266 | 0.442 | 0 | 1 |
| median_typ_curb | Indicates roadway with a curb as the median | 0.035 | 0.184 | 0 | 1 |
| sidewalk_0 | Indicates no sidewalks present | 0.748 | 0.435 | 0 | 1 |
| sidewalk_1 | Indicates sidewalk one side | 0.115 | 0.320 | 0 | 1 |
| sidewalk_2 | Indicates sidewalk on both sides | 0.136 | 0.344 | 0 | 1 |
| ltd_jt_cnd_ex | Indicates longitudinal joints in excellent condition | 0.112 | 0.316 | 0 | 1 |
| ltd_jt_cnd_fair | Indicates longitudinal joints in fair condition | 0.350 | 0.478 | 0 | 1 |
| ltd_jt_cnd_poor | Indicates longitudinal joints in poor condition | 0.535 | 0.500 | 0 | 1 |
| ltd_jt_cnd_vrypoor | Indicates longitudinal joints in very poor condition | 0.003 | 0.059 | 0 | 1 |
| turn_lanes_none | Indicates no turn lanes present | 0.490 | 0.501 | 0 | 1 |
| turn_lane_left | Indicates presence of a left turn lane | 0.122 | 0.328 | 0 | 1 |
| turn_lane_right | Indicates presence of a right turn lane | 0.105 | 0.307 | 0 | 1 |
| turn_lanes_both | Indicates presence of both left and right turn lanes | 0.283 | 0.451 | 0 | 1 |

* Standard deviation

### 5.1.7 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 2 included. Variables that proved to be insignificant were removed in a systematic fashion until only significant variables remained. Table 7 shows the modeling results acquired from STATA.

**Table 7: Statistical modeling results**

| **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 |
| **lit_night_13_14** | **Coef.** | **Std. Err.** | **z** | **P>\|z\|** | **[90% Conf. Interval]** | |
| poly | -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 |
| Likelihood-ratio test of alpha=0: | chibar2(01) = 423.57 Prob>=chibar2 = 0.000 | | | | | |

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 than 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 (e.g. HMA over concrete) 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 significantly 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% or greater.

As previously mentioned two MDOT regions, Regions Five and Six, were excluded from the selected data due to a lack of information from the guardrail inventory. Regions Two and Seven were not significantly different than Region 1, therefore they were removed from the model. Regions Three and Four showed a significant increase in nighttime crashes over Regions One, Two and Seven. 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:

$$\textit{Nighttime Crashes} = \exp(-2.159 - 0.444 * \textit{poly} + 0.027 * \textit{aadt\_1000} + 0.254 * \textit{surf\_3} + 0.047 * \textit{spd\_limit} + 0.206 * \textit{num\_}\text{lanes} + 0.192 * \textit{length} + 0.728 * \textit{turn\_lane\_right} + 0.453 * \textit{region\_3} + 0.430 * \textit{region\_4} - 0.877 * \textit{median\_typ\_concrete} - 0.868 * \textit{median\_typ\_guard} - 0.656 * \textit{median\_typ\_ditch}) \quad (3)$$

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

$$CMF_{poly} = \exp(-0.444) = 0.64 \quad (4)$$

From the CMF, the CRF can also be calculated:

$$CRF_{poly} = 1 - CMF_{poly} = 0.36 \quad (5)$$

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.

## 5.2 Cost-Benefit Analysis Methodology

As discussed in the literature review, the main benefits of delineation include aiding traffic flow, increasing driver comfort, and increasing traffic safety. Although most of these factors are not easily measurable, the most quantifiable feature is a treatment's impact in terms of crash reduction.

As with other types of infrastructure, delineation systems possess initial installation 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 utilized for this portion of the analysis.

Calculated or previously developed CMFs were used to calculate crash reduction factors (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:

$$Reduction\ in\ Crashes\ per\ Mile = CRF_i * Average\ Annual\ Crashes\ per\ mile \quad (6)$$

To quantify the reduction in crashes, the cost per crash must be applied. A study by Kostyniuk, et al (2011) *(61)* estimated a value of $19,999 as the average monetary cost for crashes occurring in Michigan. This value included consideration for medical care and emergency response as well as non-monetary costs such as impacts on individuals' quality-of-life. Annual crash savings due to a reduction in crashes was computed using the following equation:

$$Average\ Annual\ Savings\ per\ Mile = (Reduction\ in\ Crashes\ per\ Mile * Average\ Crash\ Cost) \quad (7)$$

Cost estimates for each treatment were developed using installation costs per mile. When considering alternative marking materials the cost was the differential installation cost, meaning the difference in installation costs between the current material and the alternative material. When considering the addition of systems where they were formerly absent, e.g. SRPMs, the cost included the entire installation cost.

Additionally, in order 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 costs for each treatment. For the costs, the present value (PV) was taken to be the installation cost in cases where a system was added or the differential cost if it was being improved. The discount rates used were dependent on the life span (Circular A-94 Appendix C, 2016) *(56)* of the material or treatment. The final step in the cost-benefit analysis is to develop the benefit-cost ratio (BCR) using the following equation:

$$BCR = PV_{benefits}/PV_{costs} \quad (8)$$

A BCR greater than one means that the benefits of an alternative system outweigh the costs, proving the potential to be beneficial upon implementation *(62)*. The results of the cost-benefit analyses will be discussed in greater detail in Section 5.3.3 of the report.

## 5.3 Alternative Strategy Analysis

### 5.3.1 Snowplowable Raised Pavement Markers

To perform the cost-benefit analysis for SRPMs, several assumptions were required. The average installation costs was acquired from the survey on delineation practices. An average cost of $37.89 per unit was calculated based on responses from all participants. Additionally, an average lifespan of 5.5 years was established through the survey with an associated discount rate of 2.475% (Circular A-94 Appendix C, 2016) (63). Based on a previous study, a spacing of 80 feet was assumed, resulting in 66 units per mile.

Due to the fact that SRPMs are not currently implemented in Michigan, it was necessary to apply CRFs from previous studies, documented in the CMF Clearinghouse website. One NCHRP study developed CRFs based on various levels of AADT on four-lane roadways for nighttime crashes. The study concluded that SRPMs were beneficial on roadways with an AADT greater than 20,000 *(64)*. Table 8 summarizes the calculations from the cost-benefit analysis.

Figure 52: Trinity Lightweight Raised Pavement Marker

Table 8: Results of SRPM cost-benefit analysis

| Sites | | Crash Reduction for SRPM Implementation | | | | Costs and Benefits of SRPM Implementation | | | |
|---|---|---|---|---|---|---|---|---|---|
| Number of Sites | AADT | CRF | Nighttime Crashes Per Mile (2013-2014) | Average Annual Nighttime Crashes per Mile | Average Annual Nighttime Crash Reduction per Mile | Average Annual Savings per Mile | Present Value Benefits per Mile | SRPM Installation Costs per Mile | Benefit to Cost Ratio (BCR) per Mile |
| 471 | 20,001-60,000 | 0.06 | 13.98 | 6.99 | 0.42 | $8,390 | $42,649 | $2,501 | 17.05 |
| 103 | >60,000 | 0.33 | 22.97 | 11.49 | 3.79 | $75,803 | $385,352 | $2,501 | 154.10 |

Roadways with AADT between 20,000 and 60,000 resulted in a BCR of 17.05. The greatest benefit is shown on roadways with an AADT greater than 60,000 vehicles, which is represented by a BCR of 154. Results from this analysis show a benefit to implementing SRPMs on roadways with an AADT greater than 20,000 with the most considerable benefit observed when the AADT is greater than 60,000.

### 5.3.2 Polyurea Analysis

Based on previous analysis, it was found that polyurea performed significantly different than waterborne paint. A CRF of 0.36 was calculated to show the reduction in nighttime crashes if polyurea was implemented rather than waterborne paint. To perform cost-benefit analysis, a theoretical situation was considered. All roadways that currently have waterborne paint were considered to have polyurea implemented instead. The different installation costs in Michigan were known to be $0.15 per linear foot for waterborne paint and $0.85 per linear foot for polyurea. For the analysis, the differential installation cost was considered since one material would be replacing the other. Since the cost-benefit analysis was focused on the implementation of polyurea, a lifespan of five years was used which has a corresponding discount rate of 2.4%. Table 9 shows the results of the cost benefit analysis for implementing polyurea on all sites that currently have waterborne paint.

Table 9: Polyurea implementation cost-benefit analysis results

| Crash Reduction for Polyurea Implementation | | | Costs and Benefits of Polyurea Implementation | | | | | |
|---|---|---|---|---|---|---|---|---|
| Average Nighttime Crashes Per Mile | Average Annual Nighttime Crashes per Mile | Average Annual Nighttime Crash Reduction per Mile | Average Annual Savings per Mile | Present Value Benefits per Mile | Polyurea Installation Cost per Mile | Waterborne Installation Cost per Mile | Differential Installation Cost per Mile | Benefit to Cost Ratio (BCR) per Mile |
| 4.325 | 2.162 | 0.778 | $15,569 | $72,540 | $4,488 | $792 | $3,696 | 19.63 |

Based on the analysis, polyurea is beneficial when implemented in areas that currently have waterborne paint. A BCR was calculated to be 19.63 for an average annual nighttime crash rate of 2.16 crashes per mile. In order to obtain more applicable results, the BCR was calculated for various average annual nighttime crashes rates. Figure 53 shows the result of these calculations. As the number of nighttime crashes increases, the predicted BCR also increases.

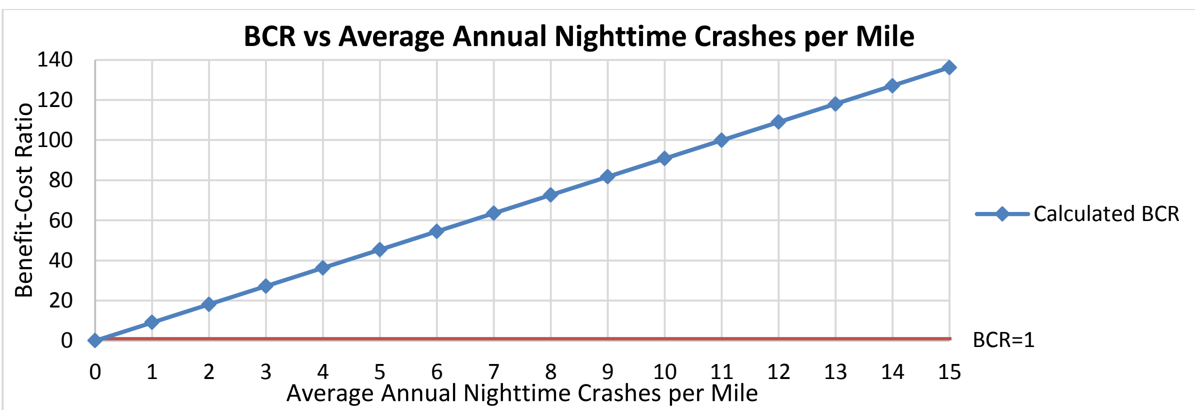



Figure 53: BCR for various annual average nighttime crash rates when implementing polyurea rather than waterborne paint

### 5.3.3 Marking Material Break-even Analysis

In order to make the marking material results more applicable, some general calculations were completed. To observe the benefit of implementing durable markings rather than waterborne paint, a lifespan of five years was considered for a theoretical material. An associated discount rate of 2.4% was included. Theoretical CRFs ranging from 0.1 to 0.8 were assumed. The break-even costs for the marking material implementation were calculated to determine the cost per linear foot when the BCR was set equal to one. Additionally, varying rates of nighttime crashes per mile were considered. These calculations are summarized in Figure 54.

Based on the calculations higher CRFs result in higher break-even costs. This means that the benefits will be higher and more expensive materials will be compensated. The findings summarized in the chart may be used when future analysis yields CRFs for alternative marking materials with a lifespan of five years. If the CRF and nighttime crash frequency are known, this chart may be used to identify the break-even cost. Any cost lower than the break-even cost will result in benefit with a BCR greater than one.

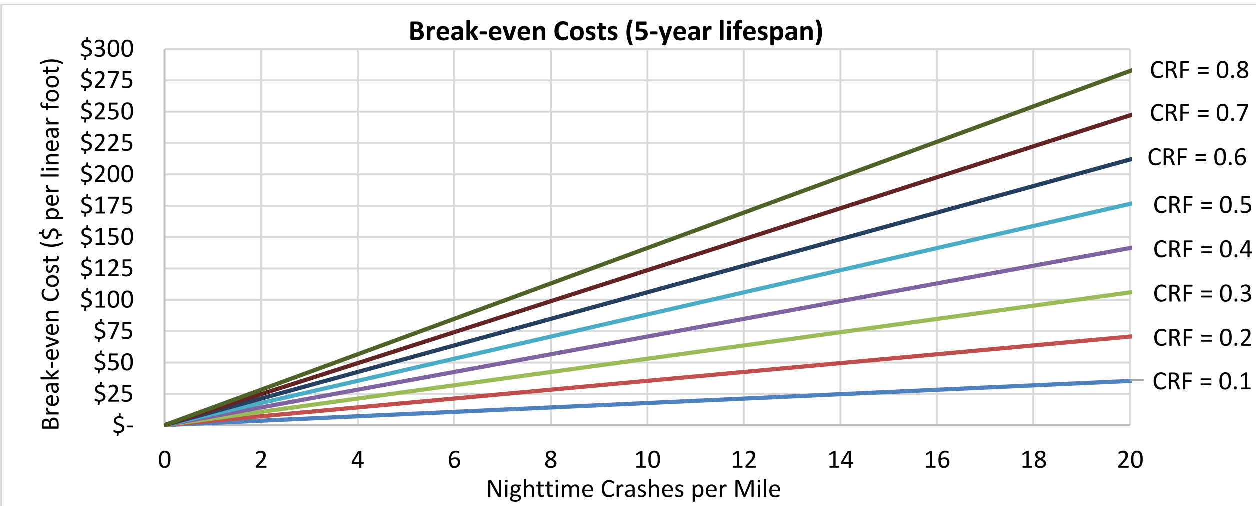



**Figure 54: Break-even costs for marking materials with varying CRFs**

### 5.3.4 Continuous Freeway Lighting

To determine the benefit of lighting in regard to costs, several assumptions were made. Only nighttime crashes were considered due to the lighting only being effective at night. Lifespan and unit cost information for the state of Michigan were not readily available. Therefore, these values were established through literature review. An installation cost of $75,000 per mile and a lifespan of 15 years were assumed. Based on the lifespan, a discount rate of 3.05% was applied. Additionally, various CRFs were used from a previous study. These values, which are summarized in Table 10, depend on the type of area and roadway *(65)*.

Table 10: Lighting CRF for nighttime crashes based on location

| CRF | Type of Roadway |
|---|---|
| 0.2 | Urban Freeway Mainline |
| | Rural Freeway Mainline |
| | Rural Intersection* |
| | Urban Intersection* |
| | Urban Mainline (5% Commercial)* |
| 0.3 | Urban Mainline (25% Commercial)* |
| 0.4 | Urban Mainline (Commercial)* |
| 0.8 | Urban Freeway Interchange |
| | Rural Freeway Interchange |
| *No access control | |

Due to limited knowledge of the location of lighting currently implemented in Michigan, the BCR was calculated using the various CRFs for a theoretical range of nighttime crashes per mile. The results of these calculations are summarized in Figure 55. It can be noted that at a frequency of two nighttime crashes per mile all types of roadways have BCRs greater than one, indicating a benefit. Lighting is especially beneficial at both urban and rural freeway interchanges, which have a CRF of 0.8.

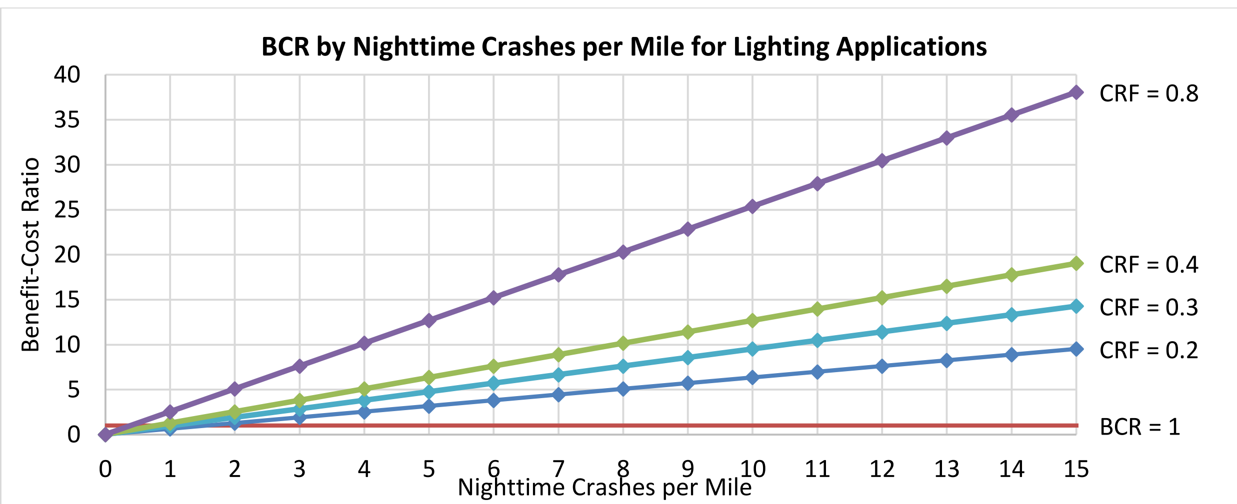


Figure 55: BCR by nighttime crash rate for lighting implementation

### 5.3.5 Recessed Markings

To analyze recessed markings several marking materials were considered, including waterborne paint, sprayable thermoplastic, and durable markings such as modified urethane and polyurea, as these materials have previously been recessed. The installation cost for these materials as well as the additional cost for recessing were known for the state of Michigan. The lifespans of each material for recessed and non-recessed applications were also known. In order to compare the costs and assess the advantage of recessing the markings the analysis was completed for the lifespan of the recess, which was taken to be five years. An associated discount rate of 2.4% was also applied. From lifespan analysis, the equivalent uniform annual cost was calculated so the material applications could be easily compared. The results of these calculations are included in Table 11.

From these results, it can be noted that the additional cost of recessing is not always offset by increased durability. A significant increase in durability is required to make recessing beneficial when only considering installation costs. Other benefits from increased durability may be experienced but are not easily measured.

**Table 11: Calculated costs for recessed and non-recessed marking material application**

| Material | Material Life Span | Equivalent Uniform Annual Cost (per mile) |
|---|---|---|
| Recessed Waterborne | 1 year | $1,234.67 |
| | 2 years | $917.96 |
| Non-Recessed Waterborne | 1 year | $792.00 |
| Recessed STP | 2 years | $1,076.39 |
| | 5 years | $664.00 |
| Non-Recessed STP | 1 year | $1,056.00 |
| Recessed MU or Polyurea | 5 years | $1,383.34 |
| Non-Recessed MU or Polyurea | 5 years | $940.67 |

# 6 Discussion

## 6.1 Components of a Successful Delineation Program

A successful delineation program includes a range of marking methods, materials, and applications to address a range of needs and scenarios. The basic components include short and long range delineation, illuminated and reflective materials, and tactile and visual methods. This range of methods and materials helps to provide options for a range of geometric and environmental conditions. Basic components of a successful delineation program include:

- Long Line Pavement Markings
- Special Pavement Markings
- Centerline and Shoulder Rumble Strips
- Supplemental Delineators
    - Guardrail and Barrier Mounted
    - Post Mounted
    - In-Pavement
    - Sign Post Mounted
- Lighting
    - High Mast Lighting
    - Intersection Lighting / Beacons
    - Supplemental Sign Lighting / Beacons

Each broad delineation category listed above includes various materials applicable for different needs and situations. For example, several different types of pavement marking material should be available for long line and special pavement markings depending on the needs and condition of any given location. Special markings in turning lanes would likely employ more durable markings as those locations tend to experience greater wear due in part to the impact of turning vehicles. Similarly, different supplemental delineators may be used depending on existing or planned infrastructure. Locations with existing barrier or guardrail would be better served by using mounted delineator systems as opposed to the installation of independent post mounted delineators.

In addition, successful programs, while flexible and employing engineering judgement, utilize a number of guidelines to help determine optimal delineation programs for specific scenarios. Some common examples include consideration of pavement condition or remaining service life at a location before selecting an appropriate marking material. Locations where a resurfacing project is occurring the following year would not be appropriate candidates for recessed markings. Another example would be the consideration of AADT at a given location. Durable pavement markings have been shown to provide a greater return on investment at locations with higher AADT while lower durability materials perform sufficiently on lower volume roads. In all cases, use of selection criteria should be based on robust research or institutional knowledge.

## 6.2 Recommendations for Implementation

When including the crash savings associated with certain delineation treatments, rather than just the costs associated with implementation, certain treatments show promise for more widespread use on Michigan's roadways.

**Consider Snowplowable Raised Pavement Markers**

Based on the positive benefits identified, consideration should be given to including snowplowable raised pavement markings on 4-lane roadways with greater than 20,000 AADT (BCR of 17.05 per mile) and especially on those segments of roadway having greater than 60,000 AADT (BCR of 154.10 per mile). In light of current concerns that available SRPMs may pose a maintenance hazard, sites that do not generally have vulnerable users (e.g. pedestrians or motorcyclists) may reduce the concern that a SRPM dislodged during plowing activities could strike an unprotected road user. Additionally, development of more lightweight versions may help to address some of the existing concerns associated with SRPMs.

**Increase Use of Polyurea Pavement Markings**

When compared to waterborne paint, polyurea pavement markings were found to potentially reduce nighttime crashes by 36 percent. On roadways averaging as few as one nighttime crash per mile, using polyurea pavement markings rather than waterborne may have significant benefits (e.g. BCR greater than one).

**Review Lighting at Freeway Interchanges**

As discussed in Section 5.3.4, lighting at interchanges is especially beneficial. MDOT should consider reviewing freeway interchanges where lighting is not present and more than one nighttime crash occurs every two years. These locations may benefit from a significant crash reduction if lighting is added where feasible.

### Improve Delineation Inventory

To better understand the potential benefits of changes to MDOT's delineation program and aid in managing an important safety asset, a greater confidence in the inventory data would reduce the uncertainty with benefit/cost calculations, and help quantify the replacement cost of delineation components – an important part of any asset management system. MDOT should identify delineation data recording process improvements such as converting spreadsheets to spatial databases and converting digital design files of proposed pavement markings to database equivalents. This would help improve the pricing accuracy of pavement marking restriping contracts as well as providing data to help identify future safety improvements.

### Implement a Regular Replacement Cycle for Delineators

Reflective sign sheeting used in lieu of reflective buttons is gaining acceptance as an effective and durable replacement. Taking into account the positive benefits that drivers – including snowplow operators – identify with these delineators, consideration should be given to replacing post-mounted delineators on a regular schedule (e.g. every seven years) or including their replacement in regularly scheduled sign replacement programs (if reflective sign sheeting is used in lieu of reflective buttons or flexible delineators are used).

### Update MDOT's Pavement Marking Selection Guidelines

MDOT should investigate updating their pavement marking selection guidelines to include additional factors including AADT and the service life of the markings when choosing between waterborne or more durable markings.

## 6.3 Recommendations for Further Research

Snowplowable raised pavement markers are used by many neighboring states, and new products are currently being trialled as part of AASHTO's National Transportation Product Evaluation Program (NTPEP). As of September 29, 2016, the NTPEP Raised Pavement Markers Committee Conference Call noted that the two-year evaluation of the Ray-O-Lite casting is nearing completion, and that Trinity Highway Products has two metal-over-plastic casting snowplowable markers which have held up over one year in the field (including the winter of 2015-2016) (*66)*. These castings weigh just over two pounds, as opposed to the prior generation of all-metal SRPMs which weigh over five pounds. If struck by a force large enough to dislodge the casting from the pavement, these lightweight SRPMs are more prone to breaking up into smaller pieces rather than becoming a large projectile. Monitoring the results of this NTPEP trial may support the future inclusion of SRPMs in MDOT's delineation strategy.

MDOT should continue evaluating other new durable marking technologies for use on Michigan's roadways. As shown in Figure 54, segments of roadway with one or more nighttime crash per mile would likely show an average BCR greater than one if a delineation product has at least a five-year lifespan.

# 7 Conclusion

This project involved the research of Michigan's and other states' delineation programs to identify the successful components and whether there is need to change how MDOT delineates the roadways under its jurisdiction.

Best practices were identified from current literature, ongoing research, and a survey of other states and Canadian provinces. MDOT's widespread use of rumblestrips – both edgeline and centerline – compare favorably with many other states.

Neighboring states identified service life, average cost, durability, and retroreflectivity as the most significant factors in regard to painted, recessed, and durable markings. Michigan mainly considers the remaining service life of the pavement and average cost when implementing painted markings, and remaining service life, impact of winter maintenance, and durability when considering recessed markings.

In the Michigan, analysis shows potential benefits for wider adaptation of polyurea pavement markings, snowplowable raised pavement markers on high-AADT roadways, and freeway lighting at interchanges.

# 8 Bibliography


1. Migletz, J., J.K. Fish, and J.L. Graham. Roadway Delineation Practices Handbook. FHWA-SA-93-001. FHWA, U.S. Department of Transportation, 1994.

2. Dravitzki, V.K., D.E. Munster, and J.N. Laing. Minimum Performance Requirements for Delineation. Central Laboratories Report 02-527450. Opus International Consultants, 2002.

3. Manual on Uniform Traffic Control Devices for Streets and Highways. 2009 Edition. U.S. Department of Transportation Federal Highway Administration.

4. Iowa Traffic Control Devices and Pavement Markings: A Manual for Cities and Counties. Section D: Pavement Markings. Center for Transportation and Research and Education, April 2001.

5. Jiang, Yi. Durability and Retro-Reflectivity of Pavement Markings (Synthesis Study), 2008. <http://docs.lib.purdue.edu/cgi/viewcontent.cgi?article=1704&context=jtrp>. Accessed June 2, 2015.

6. Montebello, D., and J. Schroeder. Cost of Pavement Marking Materials, 2000. <http://www.lrrb.org/media/reports/200011.pdf>. Accessed June 2, 2015.

7. Goldbaum, J. Cost-Benefit Evaluation of Enhanced Specifications for Epoxy Pavement Marking Material, 2010. <https://www.codot.gov/programs/research/experimentalfeatures/epoxypavementmarking.pdf>. Accessed June 2, 2015.

8. Lynde, M. Evaluation of Inlaid Durable Pavement Markings in an Oregon Snow Zone, 2006. http://www.oregon.gov/ODOT/TD/TP_RES/docs/reports/durablesreport.pdf>. Accessed June 2, 2015.

9. Migletz, J., J.L. Graham, D.W. Harwood, and K.M. Bauer. Service Life of Durable Pavement Markings. Transportation Research Board 1749. Paper No. 01-0447.

10. Migletz, J., and J. Graham. NCHRP Synthesis 306 Long-Term Pavement Marking Practices, A Synthesis of Highway Practice. Transportation Research Board, Washington, D.C., 2002.

11. Brosseau, M., Carrasquilla, A., & Saunier, N. Pavement Marking Retroreflectivity in Cold Regions: Survey of Practices, 2012. <https://www.cirrelt.ca/DocumentsTravail/CIRRELT-2012-67.pdf> Accessed June 2, 2015.

12. Government of Alberta Transportation. Use of Durable Pavement Markings, 2010. Accessed June 2, 2015.

13. Hirasawa, M., et. al. Development of Recessed Pavement Markings That Incorporate Rumble Strips. Journal of the Eastern Asia Society for Transportation Studies, vol. 8 (2010): n. pag. Web. 02 June 2015. <http://www.easts.info/publications/journal_proceedings/journal2010/100292.pdf>.

14. Roads and Transport Authority, New South Wales, Australia. Delineation, 2008. <http://www.rms.nsw.gov.au/business-industry/partners-suppliers/guidelines/complementary-traffic-material/delineation.html> Accessed June 2, 2015.

15. Technical Memorandum No. 14-11-T-02, Minnesota Department of Transportation, 2014.

16. Lyon, C., B. Persaud, and K. Eccles. Safety Evaluation of Wet-Reflective Pavement Markings. FHWA-HRT-15-065. FHWA, U.S. Department of Transportation, 2015.

17. Thamizharasan, A., W. A. Sarasua, D.B. Clarke, and W. J. Davis. A Methodology for Estimating the Lifecycle of Interstate Highway Pavement Marking Retroreflectivity. Department of Civil Engineering, Clemson University, Clemson, 2002.

18. Dwyer, C.E., W.R. Vavrik, and R.L. Becker. Evaluating Pavement Markings on Portland Cement Concrete (PCC) and Various Asphalt Surfaces. Illinois Department of Transportation, Bureau of Materials and Physical Research, Springfield, IL, 2013.

19. Aktan, F., and T.Schnell. Performance Evaluation of Pavement Markings Under Dry, Wet, and Rainy Conditions in the Field. Journal of the Transportation Research Board, No. 1877, TRB, 2004.

20. Bahar, G., M. Masliah, T. Erwin, and E. Tan. NCHRP Web-Only Document 92: Pavement Marking Materials and Markers: Real-World Relationship Between Retroreflectivity and Safety Over Time. NCHRP Project 17-28. TRB, 2006.

21. Smadi, O., N. Hawkins, I. Nlenanya, and B. Aldemir-Bektas. Pavement Markings and Safety. IHRB Project TR-580. Iowa State University Institute for Transportation, 2010.

22. Carlson, P.J., E.S. Park, and D.H. Kang. An Investigation of Longitudinal Pavement Marking Retroreflectivity and Safety. Submitted to the 92nd Annual Meeting of the Transportation Research Board, 2012.

23. Bahar, G., B. Persaud, A. Smiley, and H. McGee. Safety Evaluation of Permanent Raised Pavement Markers. NCHRP Report 518. Transportation Research Board, Washington, D.C., 2004.

24. Carlson, P.J., J.D. Miles, A.M. Pike, and E.S. Park. Evaluation of Wet-Weather and Contrast Pavement Marking Applications: Final Report. FHWA/TX-07/0-5008-2. Texas Department of Transportation, Research and Technology Implementation Office, Austin, Texas, 2007.

25. Filice, J. Study of Snowplowable Raised Pavement Markers. ABTR/RD/TM-02/06. Alberta Transportation, 2006.

26. Ibarra, C., and E. Rice. LED Raised Pavement Markers. FHWA-SA-09-007, May 2009.

27. Carlson, P., and J. Wagner. An Evaluation of the Effectiveness of Wider Edge Line Pavement Markings. Texas Transportation Institute, 2012.

28. Technical Advisory. Shoulder and Edge Line Rumble Strips. T 5040.39 Revision 1. Federal Highway Administration, 2011. http://safety.fhwa.dot.gov/roadway_dept/pavement/rumble_strips/t504039/ Accessed Nov. 23, 2015.

29. Torbic, D.J., J.M. Hutton, C.D. Bokenkroger, K.M. Bauer, D.W. Harwood, D.K. Gilmore, J.M. Dunn, J.J. Ronchetto, E.T. Donnell, H.J. Sommer III, P. Garvey, B. Persaud, and C. Lyon. Guidance for the Design

and Application of Shoulder and Centerline Rumble Strips. NCHRP Report 641. Transportation Research Board, Washington, D.C., 2009.

30. Smadi, O., and N. Hawkings. Practice of Rumble Strips and Rumble Stripes, A Synthesis of Highway Practice. NCHRP Synthesis 490. Transportation Research Board, Washington D.C., 2016.

31. Bullough, J.D., and L.C. Radetsky. Analysis of New Highway Lighting Technologies. Project No. 20-7/305. NCHRP, Transportation Research Board of The National Academies, Troy, NY, 2013.

32. Schalkwyk, I., N. Venkataraman, V. Shanker, J. Milton, T. Bailey, and K. Calais. Evaluation of the Safety Performance on Continuous Mainline Roadway Lighting on Freeway Segments in Washington State. WA-RD 8551. Washington State Department of Transportation, 2015.

33. Srinivasan, R., J. Baek, D. Carter, B. Persaud, C. Lyon, K. Eccles, F. Gross, and N. Lefler. Safety Evaluation of Improved Curve Delineation. FHWA-HRT-09-045. U.S. Department of Transportation, Federal Highway Administration, Washington, D.C., 2009.

34. Re, J.M., H.G. Hawkins, Jr., and S.T. Chrysler. Assessing Benefits of Chevrons with Full Retroreflective Signposts on Rural Horizontal Curves. In Transportation Research Record: Journal of the Transportation Research Board, No. 2149, Transportation Research Board of the National Academies, Washington, D.C., 2010, pp. 30-36.

35. Zador, P., H.S. Stein, P. Wright, and J. Hall. Effects of Chevrons, Post-Mounted Delineators, and Raised Pavement Markers on Driver Behavior at Roadway Curves. In Transportation Research Record: Journal of the Transportation Research Board, No. 1114, Transportation Research Board of the National Academies, Washington, D.C., 1987, pp. 1-10.

36. TAPCO, Traffic & Parking Control Co., Inc. Dynamic Curve Warning & Guidance Systems. http://www.tapconet.com/store/product-detail/Kebb/dynamic-curve-warning-and-guidance-systems?c=Alab&sku=2180-DCWS. Accessed Dec. 8, 2015.

37. Siddharthan, R.V., R.L. Fine, and K.E. Dennett. Study of Flexible Delineator Post Performance and Revision of Existing Pre-Qualification Specifications. P247-02-803. Nevada Department of Transportation, 2003.

38. CTC & Associates LLC, WisDOT Research & Library Unit. Flexible Delineator Posts: A Survey of Use Among State DOTs. Bureau of Technical Services Division of Transportation System Development, 2007.

39. Chrysler, S.T., J. Re, K.S. Knapp, D.S. Funkhouser, and B.T. Kuhn. Driver Response to Delineation Treatments on Horizontal Curves on Two-Lane Roads. FHWA/TX-09/0-5772-1. Texas Department of Transportation, 2009.

40. Orr, D.P., P. Stein, and J. Lampman. Effect of Painted Shoulders on Vehicle Speed. In Transportation Research Record: Journal of the Transportation Research Board, No. 2472, Transportation Research Board of the National Academies, Washington, D.C., 2015, pp. 129-133.

41. Hallmark, S.L., E. Peterson, E. Fitzsimmons, N. Hawkins, J. Resler, and T. Welch. Evaluation of Gateway and Low-Cost Treatments for Major Routes in Small Rural Communities. CTRE Project 06-185, IHRB Project TR-523. Center for Transportation Research and Education, Iowa State University, 2007.

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

43. Montebello, D., and J. Schroeder. Cost of Pavement Marking Materials, 2000.

44. Gates, T. J., H. G Hawkins, and E. R. Rose. Effective Pavement Marking Materials and Applications for Portland Cement Concrete Roadways. No. FHWA/TX-03/4150-2. Texas Transportation Institute, Texas A & M University System, 2003.

45. Hawkins, N., O. Smadi, and S. Knickerbocker. Evaluation of Pavement Markings on Challenging Surfaces. MM/RC 2016-08. Minnesota Department of Transportation, Research Services & Library, 2016.

46. Lord, D., and F. Mannering. "The statistical analysis of crash-frequency data: a review and assessment of methodological alternatives." Transportation Research Part A: Policy and Practice 44, no. 5 (2010): 291-305.

47. Roadway Lighting Design Guide. American Association of State Highway and Transportation Officials, 2005.

48. Guide for the Design of Roadway Lighting. Transportation Association of Canada, 2006.

49. Walton, D., J.A. Thomas, S.J. Murray, and M. Fourie. The effect of better road delineation: a new method of assessment. NZ Transport Agency research report 442, 2011.

50. Allen, R.W., D.T. McRuer, J.R. Hogge, R.W. Humes, A.C. Stein, J.F. O'hanlon, R.T. Hennessy, G.R. Kelley, and G.V. Bailey. Drivers' Visibility Requirements for Roadway Delineation, Volume I: Effects of Contrast and Configuration on Driver Performance and Behavior. FHWA-RD-77-165. Systems Technology, Inc., 1977.

51. Godthelp, H., and J. Riemersma. Perception of Delineation Devices in Road Work Zones During Nighttime. SAE Technical Paper 820413. Society of Automotive Engineers, 1982.

52. Rumar, K., and D.K. Marsh II. Lane Markings in Night Driving: A Review of Past Research and of the Present Situation. Technical Report UMTRI-98-50. The University of Michigan, Transportation Research Institute, 1998.

53. Schumann, J. Post-Mounted Delineators and Perceptual Cues for Long-Range Guidance During Night Driving. Technical Report UMTRI-2000-42. The University of Michigan, Transportation Research Institute, 2000.

54. Delineators. Michigan Department of Transportation. February 19, 2016. http://mdotcf.state.mi.us/public/tands/Details_Web/mdot_delineator_usage_guidelines.pdf

55. Michigan Manual on Uniform Traffic Control Devices for Streets and Highways. Revised September 2013. Michigan Department of Transportation, Michigan State Police, and U.S. Department of Transportation Federal Highway Administration. http://mdotcf.state.mi.us/public/tands/Details_Web/mmutcdcompleteinteractive_2017.pdf

56. Pavement Markings. Michigan Department of Transportation. Various dates. < http://mdotcf.state.mi.us/public/tands/plans.cfm>

57. Road Design Manual. Michigan Department of Transportation. < http://mdotcf.state.mi.us/public/design/englishroadmanual/> Accessed December 22, 2016.

58. 2012 Standard Specifications for Construction. Michigan Department of Transportation. < http://mdotcf.state.mi.us/public/specbook/2012/>

59. Special Provisions. Michigan Department of Transportation. <http://mdotjboss.state.mi.us/SpecProv/specProvHome.htm>

60. Lutkevich, P., D. McLean, and J. Cheung. FHWA Lighting Handbook. Federal Highway Administration, Washington, D.C., 2012.

61. Kostyniuk, L. P, L. J. Molnar, R.M. St. Louis, N. Zanier and D. W. Eby. (2011). Societal Costs of Traffic Crashes and Crime in Michigan. Available at www.michigan.gov/documents/msp/2011_Crash_and_Crime_Final_Report_361083_7.pdf.

62. Kwigizile, V., J. Oh, R. Van Houten, D. Prieto, R. Boateng, L. Rodriguez, A. H. Ceifetz, J. Yassin, J. Bagdade, and P. Andridge. Evaluation of Michigan's Engineering Improvements for Older Drivers. No. RC 1636. Transportation Research Center for Livable Communities, Western Michigan University, 2015.

63. "Circular A-94 Appendix C". 2016. The White House. Accessed November 9 2016. https://www.whitehouse.gov/omb/circulars_a094/a94_appx-c.

64. Bahar, G., B. Persaud, A. Smiley, and H. McGee. Safety Evaluation of Permanent Raised Pavement Markers. NCHRP Report 518. Transportation Research Board, Washington, D.C., 2004.

65. Florida Department of Transportation (FDOT), 2013. Lighting Justification Report. Florida: Florida Department of Transportation, District Six.

66. "NTPEP RPM Committee Conference Call". September 29, 2016. Accessed October 24 2016. http://www.ntpep.org/Documents/Technical_Committee/RPM/Minutes/NTPEP%20RPM%20Conference%20Call%20Sept%202016.pdf.

# 9 Appendices

## 9.1 Survey Questionnaire

*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 Kwigizile 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**

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.

| Selection Criteria | Very Insignificant | Insignificant | Neutral | Significant | Very Significant | Not Considered |
|---|---|---|---|---|---|---|
| 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 | ❑ | ❑ | ❑ | ❑ | ❑ | ❑ |

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.

| | Minimum | Average | Maximum |
|---|---|---|---|
| Service Life (years) | | | |
| Unit Price (US dollars per "unit") | | | |

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?

***Question 5 is only shown if "Recessed Markings" was checked in Question 2.*

**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.

| Selection Criteria | Very Insignificant | Insignificant | Neutral | Significant | Very Significant | Not Considered |
|---|---|---|---|---|---|---|
| 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 | ❑ | ❑ | ❑ | ❑ | ❑ | ❑ |

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.

| | Minimum | Average | Maximum |
|---|---|---|---|
| Service Life (years) | | | |
| Unit Price (US dollars per "unit") | | | |

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.

| Selection Criteria | Very Insignificant | Insignificant | Neutral | Significant | Very Significant | Not Considered |
|---|---|---|---|---|---|---|
| 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 | ❑ | ❑ | ❑ | ❑ | ❑ | ❑ |

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.

| | Minimum | Average | Maximum |
|---|---|---|---|
| Service Life (years) | | | |
| Unit Price (US dollars per "unit") | | | |

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.

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

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.

| Selection Criteria | Very Insignificant | Insignificant | Neutral | Significant | Very Significant | Not Considered |
|---|---|---|---|---|---|---|
| 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 | ❑ | ❑ | ❑ | ❑ | ❑ | ❑ |

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.

| | Minimum | Average | Maximum |
|---|---|---|---|
| Service Life (years) | | | |
| Unit Price (US dollars per "unit") | | | |

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 SNOWPLOWABLE RAISED PAVEMENT MARKINGS over other delineation systems in your jurisdiction? Indicate significance; indicate "Not Considered" if the criteria is not considered.

| Selection Criteria | Very Insignificant | Insignificant | Neutral | Significant | Very Significant | Not Considered |
|---|---|---|---|---|---|---|
| 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 | ❑ | ❑ | ❑ | ❑ | ❑ | ❑ |

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

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.

| | Minimum | Average | Maximum |
|---|---|---|---|
| Service Life (years) | | | |
| Unit Price (US dollars per "unit") | | | |

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.

| Selection Criteria | Very Insignificant | Insignificant | Neutral | Significant | Very Significant | Not Considered |
|---|---|---|---|---|---|---|
| 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 | ❑ | ❑ | ❑ | ❑ | ❑ | ❑ |

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.

| | Minimum | Average | Maximum |
|---|---|---|---|
| Service Life (years) | | | |
| Unit Price (US dollars per "unit") | | | |

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.

| Selection Criteria | Very Insignificant | Insignificant | Neutral | Significant | Very Significant | Not Considered |
|---|---|---|---|---|---|---|
| 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 | ❑ | ❑ | ❑ | ❑ | ❑ | ❑ |

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.

| | Minimum | Average | Maximum |
|---|---|---|---|
| Service Life (years) | | | |
| Unit Price (US dollars per "unit") | | | |

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.

| Selection Criteria | Very Insignificant | Insignificant | Neutral | Significant | Very Significant | Not Considered |
|---|---|---|---|---|---|---|
| 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 | ❑ | ❑ | ❑ | ❑ | ❑ | ❑ |

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.

| | Minimum | Average | Maximum |
|---|---|---|---|
| Service Life (years) | | | |
| Unit Price (US dollars per "unit") | | | |

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.

| Selection Criteria | Very Insignificant | Insignificant | Neutral | Significant | Very Significant | Not Considered |
|---|---|---|---|---|---|---|
| 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 | ❑ | ❑ | ❑ | ❑ | ❑ | ❑ |

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.

- Yes
- No

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.

| | Minimum | Average | Maximum |
|---|---|---|---|
| Service Life (years) | | | |
| Unit Price (US dollars per "unit") | | | |

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.

| Selection Criteria | Very Insignificant | Insignificant | Neutral | Significant | Very Significant | Not Considered |
|---|---|---|---|---|---|---|
| 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 | ❑ | ❑ | ❑ | ❑ | ❑ | ❑ |

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.

| | Minimum | Average | Maximum |
|---|---|---|---|
| Service Life (years) | | | |
| Unit Price (US dollars per "unit") | | | |

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!