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Improved Highway Lane Reflectorized Markers



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<p>16. Abstract</p> <p>The purpose of this synthesis project is to investigate alternatives and best practices in reflectorized snowplowable pavement marker technology. A survey was conducted among peer DOTs and Canadian provinces. The respondents answered questions pertaining to reflectorized marker installation practices, effectiveness of these markers and satisfaction with the current practices. All responses were summarized. Most state agencies reported the use of temporary markers and raised markers. Among the states that use snowplowable raised pavement markers, some are not completely satisfied and are seeking alternate technologies. Failure of snowplowable raised pavement markers is attributed to snowplowing operations. Several agencies suggest the use of alternative snowplow blade technologies to reduce pavement marker damage. State agencies that have installed recessed pavement markers include Alaska, Illinois, Maine, South Carolina, Arkansas, Utah, Maryland, New Mexico, Virginia, Kansas, Oregon, West Virginia, and Pennsylvania. Among these states, Alaska, Illinois, Maine, South Carolina, Arkansas, Utah, Maryland, New Mexico, and Virginia responded to the survey. Most of these states are conducting ongoing trials of recessed markers. Maryland and Virginia were the only two states that demonstrated a high satisfaction rate with recessed snowplowable markers. The authors recommend that MassDOT follow up with those state agencies that use snowplowable recessed markers, acquire the results from the recessed pavement marker trials when completed, and investigate the applicability to Massachusetts conditions. The authors also encourage MassDOT to invest in the technologies of the future, such as LED markers and solar powered LED markers, which would benefit the agency in the long run.</p>			
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Improved Highway Lane Reflectorized Markers

Final Report

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Disclaimer

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

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List of Acronyms

Acronym	Expansion
AADT	Annual Average Daily Traffic
AASHTO	American Association of State Highway and Transportation Officials
ADT	Average Daily Traffic
AMF	Accident Modification Factor
DOT	Department of Transportation
EUAC	Equivalent Uniform Annual Cost
FHWA	Federal Highway Administration
FDOT	Florida Department of Transportation
HMA	Hot Mix Asphalt
ILDOT	Illinois Department of Transportation
INDOT	Indiana Department of Transportation
JTRP	Joint Transportation Research Program
LED	Light Emitting Diode
MassDOT	Massachusetts Department of Transportation
MUTCD	Manual on Uniform Traffic Control Devices
NCHRP	National Cooperative Highway Research Program
NTPEP	National Transportation Product Evaluation Program
ODOT	Oregon Department of Transportation
PCC	Portland Cement Concrete
PennDOT	Pennsylvania Department of Transportation
PRPM	Permanent Raised Pavement Marker
QPL	Qualified Products List
RDPH	Roadway Delineation Practices Handbook
RPM	Raised Pavement Marker
RRPM	Raised Reflective Pavement Marker
SPR	Statewide Planning and Research
SRPM	Snowplowable Raised Pavement Marker
TADT	Truck Average Daily Traffic
TxDOT	Texas Department of Transportation

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Executive Summary

This study of Improved Highway Lane Reflectorized Markers was undertaken as part of the Massachusetts Department of Transportation (MASSDOT) Research Program. This program is funded with Federal Highway Administration (FHWA) Statewide Planning and Research (SPR) funds. Through this program, applied research is conducted on topics of importance to the Commonwealth of Massachusetts transportation agencies.

The purpose of this synthesis project is to investigate alternatives and best practices in reflectorized pavement markers technology. The scope of this synthesis project includes the following tasks:

- Conduct a literature review about the current practices adopted by various state agencies for road delineation using pavement markers.
- Categorize these pavement markers and describe their pros and cons.
- Conduct a survey among peer states in the United States and some provinces in Canada to better understand reflectorized marker installation practices.
- Summarize the findings of the survey and provide recommendations to MassDOT about pavement marker installations.

In 2008, MassDOT began using recessed reflectorized pavement markings to help road users delineate highway lanes at night. While these markers addressed some of the concerns over previously used snowplowable raised pavement markers, there continues to be numerous issues with their performance. The recessed pavement markers require grooving of the pavement surface and are affixed to the pavement using an epoxy adhesive. This causes the pavement depth of the surface course to be reduced at the location of the slotted pavement markers and allows for the build-up of debris within the pavement grooves. Some slotted pavement markers may lose their bond with the pavement surface due to roadway use, freeze-thaw conditions, drainage issues, roadway salt intrusion, improper installation, etc. The effort of replacing missing markers can lead to considerable maintenance costs. Moreover, there is a safety concern with missing reflectors, as well as with certain types of unattached pavement markers having the potential of becoming projectiles with possible damage to vehicles and injuries to motorists. MassDOT is interested in maximizing performance and length of service while minimizing lifecycle costs.

A survey was conducted among peer DOTs and Canadian provinces. The respondents answered questions pertaining to reflectorized marker installation practices, effectiveness of these markers, and satisfaction with the current pavement marker technology being used. All responses were summarized.

Illinois, Indiana, Ohio, Texas, Arkansas, Maryland, Louisiana, New Mexico, and Virginia reported the use of snowplowable raised pavement markers (SRPMs). Some states are not completely satisfied and are seeking alternate technologies. Several agencies attribute pavement marker failure to snowplowing practices and are looking for alternative snowplow blades that cause less damage.

State agencies that have installed snowplowable recessed pavement markers include Alaska, Illinois, Maine, South Carolina, Arkansas, Utah, Maryland, New Mexico, Virginia, Kansas, Oregon, West Virginia, and Pennsylvania. Among these states, Alaska, Illinois, Maine, South Carolina, Arkansas, Utah, Maryland, New Mexico, and Virginia responded to the survey. Most of these states are conducting ongoing trials of recessed markers. Maryland and Virginia were the only two states that demonstrated a high satisfaction rate with recessed markers. The authors recommend that MassDOT follow up with those state agencies that use snowplowable recessed markers, acquire the results from the recessed pavement marker trials when completed, and investigate their applicability to Massachusetts conditions.

The authors also encourage MassDOT to investigate technologies of the future, such as LED pavement markers and solar powered LED pavement markers, which would benefit the agency in the long run. These markers are self-luminous, lightweight, and easy to install. They can be anchored or adhered to the pavement and are relatively easy to replace. Since no slots are required for installation, water, snow, and debris do not collect around these markers. Additionally, these markers are self-luminous and maintain high visibility. Washington State has begun a test run with LED markers. LED marker technology has proven to be very effective on airport runways, and the authors recommend that MassDOT consider LED markers as a viable alternative for delineating Massachusetts roadways.

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1.0 Introduction

This study of Improved Highway Lane Reflectorized Markers was undertaken as part of the Massachusetts Department of Transportation (MassDOT) Research Program. This program is funded with Federal Highway Administration (FHWA) Statewide Planning and Research (SPR) funds. Through this program, applied research is conducted on topics of importance to the Commonwealth of Massachusetts transportation agencies.

The purpose of this synthesis project is to investigate alternatives and best practices in reflectorized pavement markers technology. The scope of this synthesis project included the following tasks:

- Conduct a literature review about the current practices adopted by various state agencies for road delineation using pavement markers.
- Categorize these pavement markers and describe their pros and cons.
- Conduct a survey among peer states in the United States and some provinces in Canada to better understand reflectorized marker installation practices.
- Summarize the findings of the survey and provide recommendations to MassDOT about pavement marker installations.

In 2008, MassDOT began using recessed reflectorized pavement markers to help road users delineate highway lanes at night. While these markers addressed some of the concerns over previously used snowplowable raised pavement markers, there continue to be numerous issues with their performance. The recessed pavement markers require grooving of the pavement surface and are affixed to the pavement using an epoxy adhesive. This causes the pavement depth of the surface course to be reduced at the location of the slotted pavement markers and allows for the buildup of debris within the pavement grooves. Some slotted pavement markers may lose their bond with the pavement surface due to roadway use, freeze-thaw conditions, drainage issues, roadway salt intrusion, improper installation, etc. The effort of replacing missing markers can lead to considerable maintenance costs. Moreover, there is a safety concern with missing reflectors, as well as with certain types of unattached pavement markers having the potential of becoming projectiles with possible attendant damage to vehicles and injuries to motorists. MassDOT is interested in maximizing performance and length of service while minimizing lifecycle costs.

The synthesis project was divided into the following five tasks:

Task 1: General Literature Review.

Review the literature on the state of the practice for alternative pavement markings, including pavement markings in development. Develop a summary of findings.

Task 2: Survey of Peer States.

Review the technical literature and survey the practices of the DOTs of the six New England states, as well as other states and provinces with relevant experience in pavement markings. Information to be collected will include the following:

- The type of pavement marker being used in these states
- Installation specifications
- Maintenance procedures

For each type and installation method, collect the following information, where available:

- Initial cost
- Reflectivity under various conditions and after various periods of time
- Maintenance issues and costs
- Actual or expected life span

Task 3: Interim Report.

Prepare an interim report on the findings related to alternative pavement marking types, implementation specifications, and maintenance processes. Alternatives should be assessed in terms of performance, cost, and life span. Include any other relevant information that would help MassDOT select an alternative to its current practice. Include a discussion of knowledge gaps.

Task 4: Implementation Recommendations.

Develop an implementation plan in collaboration with the MassDOT Technical Working Group that includes recommendations on how MassDOT should proceed given the findings from the research.

Task 5: Technology Transfer.

If appropriate, develop training materials and present findings to a maximum of ten staff persons.

Task 6: Final Report.

Prepare final report that includes deliverables from Tasks 2 to 5. The final report should include an appendix with DOT pavement marking specifications for the comparison states.

1.1 Background

1.1.1 Pavement Markers

The *Manual on Uniform Traffic Control Devices* (MUTCD)¹ allows the use of pavement markers as a supplement to traditional longitudinal markings. Pavement markers are manufactured, reflectorized devices that provide roadway delineation at night, during inclement weather and in areas where roadway alignment variations require guidance that cannot be achieved by pavement markings alone. It is important to note that pavement markers cannot be used as a replacement for standard pavement markings.

Pavement markers are composed of two major components: a base material that is designed to resist impacts from traffic, and an adherent surface securing the marker to the roadway.

1.1.2 Types of Pavement Markers

Some agencies use a series of hard, non-reflectorized raised markers to form a line where overhead lighting is available. Other agencies require that all pavement markers be reflectorized. The reflective surface can either be reflective sheeting or a prismatic reflector. The outer cover of the prismatic area can be either plastic or glass. The most common types of pavement markers are raised temporary, recessed non-snowplowable, and raised snowplowable.

Raised Temporary Markers

Raised temporary markers are the most commonly used for construction zone markings. They are commonly referred to as “raised temporary markers” or “RPMs.” Temporary pavement markers are often required in transition areas of work zones that encroach upon the traveled roadway for a period of more than two days, and in other areas as required by the engineer. They are glued to the roadway with a bitumen or epoxy adhesive. Most markers of this type consist of a plastic body with a reflective surface. Specifications require that these pavement markers be replaced when they become damaged or have been removed by traffic. These markers are required to be inspected on a routine basis and replaced as necessary.

Another general type of temporary raised marker is the “peel and stick type”. These markers generally have a paper backing that is removed to expose a butyl/adhesive pad. The marker is then applied to the roadway and firmly pressed in place. Figures 1 and 2 show a variety of raised temporary markers.

Figure 1: Temporary Raised Markers



***Source: Centerline Highway Supply Products**

Figure 2: Peel and Stick Temporary Raised Marker



***Source: Pavement Marking Tape Inc.**

Recessed Snowplowable Marker System

In a recessed snowplowable marker system, a tapered slot is cut into the roadway and a marker similar to the raised marker is affixed in the slot using epoxy or other approved adhesive. This design allows the snowplow blade to slide over the slot and not contact the marker, since it is located just below the roadway surface.

These markers are used effectively where there is sufficient traffic speed (35 mph or more) to remove any water and/or dirt that may collect on or in front of the marker lenses. This type

of marker has a plastic body with a reflective surface. Figure 3 shows a recessed snowplowable pavement marker.

Figure 3: Recessed Snowplowable Pavement Marker



*Source: TRA Inc.

Raised Snowplowable Marker System

A raised snowplowable marker system usually consists of a reflective marker glued into a protective steel or cast-iron casting. This casting is applied with epoxy into a groove that is cut in the pavement surface. The system is designed to enable a snowplow blade to ride up and over the reflective marker, leaving it undamaged. The reflective lens can be replaced in the casting using approved adhesive. Figure 4 shows an example of a raised snowplowable marker system.

Figure 4: Raised Snowplowable Permanent Markers



*Source: Highway Markers Inc.

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2.0 Literature Review

This section reviews several reports available in the literature on raised and recessed pavement markers. The findings and the conclusions drawn from each of these reports are summarized herein. These reports provide only a limited overview of the current state-of-the-practice in pavement markers. It will be the objective of subsequent tasks to obtain a more comprehensive view through a survey of state practices.

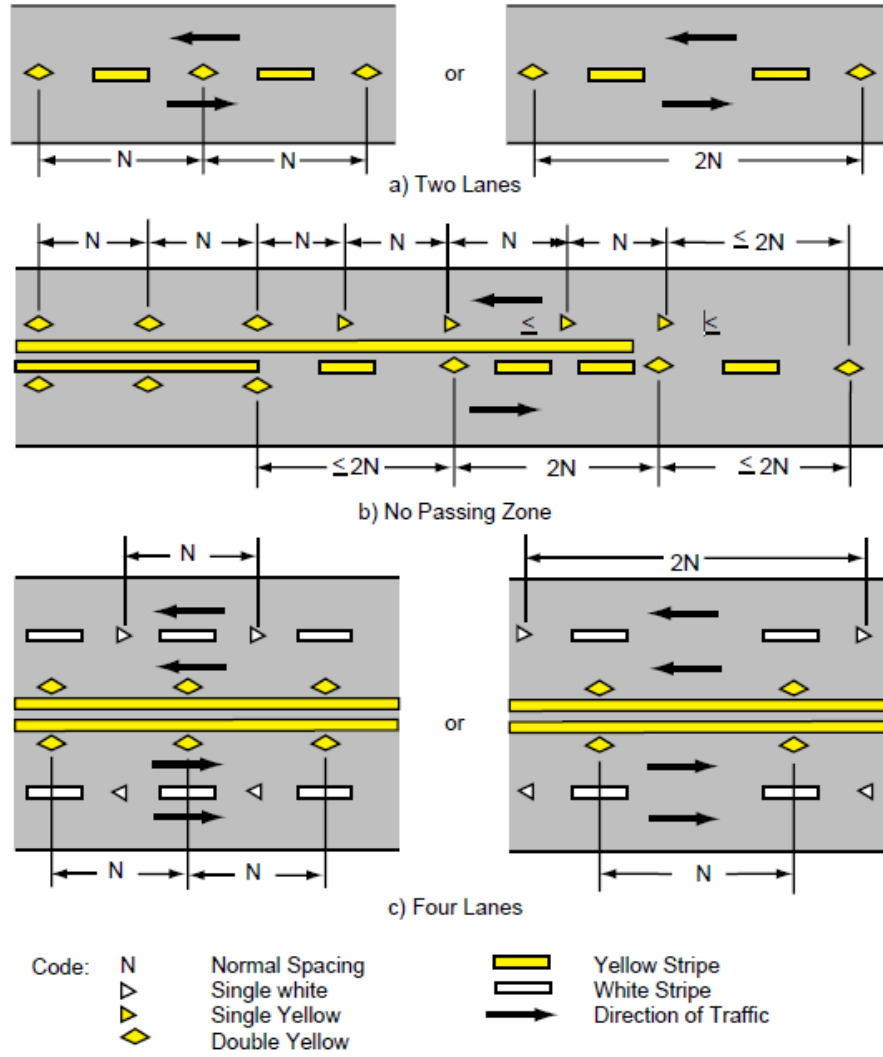
The MUTCD and the *Roadway Delineation Practices Handbook* (RDPH)¹ provide guidelines on color, materials, installation, and spacing requirements for both reflective and non-reflective pavement markers. Chapter 3B of the MUTCD¹ defines permanent raised pavement markers (PRPMs) as devices that are intended to be used as positioning guides or to supplement or substitute for pavement markings. RDPH provides guidelines specifically for using raised markers in different roadway infrastructure elements, such as horizontal curves, intersections, straight segments, and tangent ramps. It provides guidelines for different roadway types, such as two-lane roadways, four-lane undivided roadways, four-lane divided roadways, etc. The *Traffic Control Devices Handbook*⁸ recognizes PRPMs as providing excellent visibility at night and during rain. PRPMs are discussed from a materials standpoint, and no guidance is provided on when PRPMs should be used.

A study performed by the University of Iowa for the Federal Highway Administration (FHWA) provides guidelines for the installation of PRPMs. They should be installed as follows:

- To supplement double yellow centerlines on two-lane curves.
- To delineate centerlines and edge lines where there are pavement width reductions at a narrow bridge.
- At painted exits and bifurcations.
- On all freeways and Interstate highways and on state highways determined by the Bureau of Traffic Engineering based on accident data. These PRPMs are required to be snowplowable PRPMs.
- Snowplowable PRPMs should not be installed on interchange ramps.

The FHWA has published a handbook on roadway delineation practices. Figure 5 shows the common installation specification for RPMs.

Figure 5: RPMs Supplementing Pavement Markings



Note: "N" is the combined length of one line segment and one gap in a broken line configuration appropriate to the road under consideration. "N" varies between 4.5 m and 12 m, as described in Section 3.4.

*Source: U.S. Federal Highways Administration, *Roadway Delineation Practices Handbook*

The findings from individual reports are summarized in the following section.

2.1. NCHRP Report 518 – Safety Evaluation of Permanent Raised Pavement Markers

NCHRP Report 518¹⁰ presents the findings of an NCHRP research project to evaluate the safety performance of snowplowable permanent raised pavement markers (PRPMs) on two-lane roadways and four-lane freeways and to develop guidelines for their use. An analytical

procedure relying on safety performance functions or crash prediction models for roadways with and without PRPMs was developed to determine the potential cost-effectiveness of implementing PRPMs at specific locations.

To achieve these objectives, data related to snowplowable PRPMs at non-intersection locations along two-lane roadways, four-lane divided expressways, and four-lane freeways from six U.S. states (Illinois, Missouri, Pennsylvania, New York, Wisconsin, and New Jersey) were collected. These data were used to develop statistical models of their crash experience. The analysis showed that the nonselective implementation of PRPMs on two-lane roadways, overall, does not significantly reduce total or nighttime crashes, nor does it significantly increase these crash types. On the other hand, for those locations where PRPMs were implemented on the basis of selective policies (e.g., poor crash history, among other criteria), the analyses produced mixed results. Positive effects were found in New York for total and nighttime crashes where PRPMs were installed at locations selected on the basis of the wet weather nighttime crash history. Similar safety effects were not found in Pennsylvania, where PRPMs were implemented at locations selected on the basis of total nighttime crash history. The analysis results have also revealed that selective implementation of PRPMs requires a careful consideration of traffic volumes and roadway geometry (degree of curvature). At low volumes, PRPMs can in fact be associated with a negative effect, which is magnified by the presence of sharp curvatures. For example, for PRPMs installed on roadways with average annual daily traffic (AADT) ranging between 5,000 and 15,000 vehicles/day and with a degree of curvature greater than 3.5, an increase of nighttime crashes of 26% can be estimated from the model. Overall, the installation of PRPMs at non-interchange locations on four-lane freeways showed neither a positive nor a negative overall safety effect on total and nighttime crashes. However, some significant reductions were recorded for wet weather crashes at locations on four-lane freeways, and there are indications that PRPMs are only effective in reducing nighttime crashes where the AADT exceeds 20,000 vehicles/day. The results from the statistical analyses were used to develop guidelines for the use of snowplowable PRPMs for two-lane roadways and four-lane freeways, and modifications were proposed for future editions of the MUTCD.

Table 1 summarizes the results of seven relevant evaluations of the safety effects of PRPMs, measured in terms of reductions or increases in crashes. There is evidence that PRPMs affect driver behavior during daytime as well, manifested by changes in positioning in the lane and significant reductions in lane encroachments, which would be expected to impact both head-on and run-off-road crashes. Consequently, the use of daytime crashes as a comparison group in this table is questionable. It shows both significant reductions and increases in crash frequency. Indeed, the two largest studies in this group show opposing effects—one with 662 treatment locations (Georgia) showing a 22% reduction in nighttime crashes, and the other with 452 treatment locations (Texas) showing a 15% to 31% increase in nighttime crashes. There are mixed findings with respect to speed, and there is an indication that speed effects may be site specific. Changes in speed, along with the effects of PRPMs on daytime encroachments, may be factors in the mixed safety effects.

Table 1: Summary of Literature on the Safety and Effectiveness of PRPMs (*)

Study Ref. Location	Site Type	Installation Location	I- Installation Period B-Before-Period Length A-After-Period Length	Dependent Variable	Independent Variables Analyzed	Comparison Group	Other Notes	Estimated Effects
Wright et al., 1982 (13) Georgia	Horizontal curves on two-lane highways in excess of 6 degrees of curvature	Centerline	I-1976–1978 B-1–3 years A-2–4 years	Total nighttime crashes	ADT, degree of curvature	Total daytime crashes	Both raised and recessed reflective markers were used; at some locations warning signs, chevron markers, or other guidance devices were installed	22% reduction in nighttime crashes; single-vehicle crashes reduced 12% more than other nighttime crashes; reductions independent of ADT or horizontal curvature for curves with degree of curve greater than 6
Kugle et al., 1984 (11) Texas	Two-, three-, four-, five -, and six-lane roadways	Does not specify	I-1977–1979 B-2 years A-2 years	Total nighttime crashes, some analysis by crash and severity	ADT, number of lanes, number of wet weather days	Total daytime crashes	None	15% to 31% increase in nighttime crashes; no significant effect on wet weather crashes
Mak et al., 1987 (14) Texas	Two-, three-, four-, five -, and six-lane roadways	Does not specify	I-1977–1979 B-2 years A-2 years	Total nighttime crashes, some analysis by crash and severity types	Intersection type, within/outside city, horizontal curvature, grade, structures, number of lanes, divided/undivided	Total daytime crashes	Used a subset of the data from Kugle et al., 1984 (11)	4.6% of locations showed significant reductions; 10.3% showed significant increases; 85.1% showed no significant effects
Griffin, 1990 (15) Texas	Two-, three-, four-, five -, and six-lane roadways	Does not specify	I-1977–1979 B-2 years A-2 years	Total nighttime crashes	None	Total daytime crashes	Used a subset of the data from Kugle et al., 1984 (11)	16.8% increase in nighttime crashes, with the 95% confidence interval between a 6.4 and 28.3% increase.
Pendleton, 1996 (16) Michigan	Divided and undivided arterials	Centerline on undivided arterials, lane lines on divided arterials	I-1989 B-2 years A-2 years	Total nighttime crashes	Divided/undivided and VMT (vehicle miles traveled) used in empirical Bayes analysis	Total daytime crashes, total nighttime crashes at comparison sites	None	No significant effect; direction of effect positive or negative dependent on method used and access control
New York State DOT, 1989, 1997 (17, 19) New York	Suburban and rural roadways	Does not specify	I-unknown B-unknown A-unknown	Total crashes, total nighttime crashes	None	None	Regression to the mean is cited as being a factor	26% decrease in nighttime crashes when placed selectively; no significant effect when installed non selectively
Orth-Rodgers and Associates, Inc., 1998 (18) Pennsylvania	Interstate highways in rural non-illuminated areas	Does not specify	I-1992–1995 B-1–3 years A-1–3 years	Total nighttime crashes, nighttime wet road, nighttime wet road sideswipe fixed-object	None	Total daytime crashes, daytime wet road, daytime wet road sideswipe or fixed-object	Both raised and recessed reflective markers were used	18.1% overall increase in nighttime crashes; nighttime wet condition crashes increased from 30% to 47%; nighttime wet road sideswipe or fixed-object increased by 56.2%

***Reference numbers in this table refer to the original NCHRP report**

Snowplowable Pavement Markers. There are two types of snowplowable pavement markers: raised and recessed. State surveys and literature reviews have shown that recessed markers are not as popular as raised markers are. Some of the states that have installed or were installing (as of 2004) recessed markers were Kansas, Maine, Maryland, Oregon, Virginia, West Virginia, and Pennsylvania. These states, with the exception of Oregon, also installed raised snowplowable pavement markers. Illinois, Indiana, Massachusetts, Michigan, New York, Ohio, and Wisconsin almost exclusively used raised snowplowable markers.

Hofmann and Dunning¹¹ found that although recessed snowplowable markers last on average 12 months longer than raised snowplowable pavement markers, they did not perform as well as raised markers. This finding confirmed Endres's¹² conclusion that raised pavement markers outperform recessed markers under both dry and wet weather conditions. A variety of problems are associated with recessed markers because the collection of debris, rain, and snow in the recessed slots obscures the reflective surface of the markers. Pigman and Agent¹³ evaluated the performance of recessed snowplowable markers by observing the marker's visibility during snow and ice conditions. It was found that following snowplow operations, the groove retained snow and ice. However, because of the passing traffic, the snow and ice melted, and the water was swept away in a short period of time. They also observed that vehicle tires cleansed the top third of the marker, but the bottom portion remained obscured. It was concluded that although nighttime visibility was reduced, the recessed markers remained visible. The state of Maine ceased the installation of recessed markers, because when the recessed grooves became filled with snow and ice, the markers were ineffective. Investigations by Pennsylvania DOT found that recessed markers on downgrades were not as visible as recessed markers on inclines if water accumulated in the recessed slots. As a result, PennDOT decided to stop the installation of recessed markers on its roadways.

Implementation Criteria. Several states have developed their own PRPM installation criteria. The majority of surveyed states implemented PRPMs at locations with actual or potentially poor safety records. In Maryland, PRPMs were implemented where the crash rate for "correctable" guidance-related crashes was significantly higher than the statewide average on similar road types. In the states of Ohio, Texas, and California, PRPMs were installed non-selectively on all state-maintained highways. Other states—such as Maryland, Massachusetts, Wisconsin, Pennsylvania, Illinois, Indiana, and Kansas—had a combination of selective and non-selective implementation practices.

PRPMs were implemented non-selectively on certain roadway types, such as freeways, and selectively on other roadway types, on the basis of one or more of the following parameters:

- Roadway type
- Traffic volume
- Illumination
- Safety record
- Speed limits
- Horizontal curves

Missouri, Pennsylvania, and Massachusetts implemented PRPMs on all freeways. Michigan’s PRPM guidelines recommend implementation on all freeways that lack roadway illumination. The criteria for implementing PRPMs in Illinois, Indiana, and Kansas relate to traffic volume thresholds for different roadway types. PRPMs are only installed on roadways where the average daily traffic (ADT) volumes exceed these thresholds. Table 2 provides a summary of the traffic volume thresholds for different roadway types in those states.

Table 2: PRPM Guidelines Based on Traffic Volume for Different Roadway Types

State	Guidelines for rural two-lane roadways	Guidelines for multilane roadways
Illinois	ADT > 2,500 veh/day	ADT > 10,000 veh/day
Indiana	ADT > 2,500 veh/day	ADT > 6,000 veh/day
Kansas	ADT > 3,000 veh/day and TADT > 450 veh/day	

ADT = Average Daily Traffic (both directions)

TADT = Truck Average Daily Traffic

***Source: iTRANS state practices survey**

2.2. Oregon DOT – Evaluation of Raised and Recessed Pavement Markers¹⁰

Oregon DOT has been using recessed markers on all types of roads, west of the Cascade Mountains. The recessed markers are protected from snowplowing operations and may stay in place longer than raised markers; however, their life expectancy or effectiveness have not been evaluated. Standing water and/or debris have been observed in the recessed grooves, which reduces the reflectivity of the markers. In addition, the effect of studded tire wear, abrasion from sanding materials, and traffic on markers has not been fully evaluated.

A research study was initiated by Hofmann and Dunning¹¹ in July 1994 to evaluate marker use in Oregon. The study included a literature review, a survey of marker users in Oregon and adjacent states, a cost analysis, conclusions, and recommendations.

The objectives of the project were to:

- Determine the reflective life of pavement markers.
- Determine the lifecycle costs of alternative marker treatments.
- Recommend applications of markers based on traffic volume and road alignment.

Based on the information received from eight ODOT offices, it was concluded that recessed markers last, on average, 9 to 18 months longer than raised markers, the average life of a raised marker being 24 months, and the average useful life of a recessed marker being approximately 36 months. The anticipated useful life of the markers has a direct correlation between ADT, the number of times the roadway is sanded and plowed, and the number of studded tire passes. The regions east of the Cascades did not use raised or recessed markers.

In eastern Oregon, traditional striping is more cost effective, given the amount of plowing and sanding that occurs in the winter months.

Observations pertaining to the effectiveness of pavement markers have been made in various locations around the state and in other states with similar climatic conditions. Generally, both raised and recessed pavement markers provided better lane delineation than traditional striping in adverse weather conditions. Recessed markers, though, have displayed several operational problems. Problems have included collecting water, snow, sand, ice, and debris in the grooves. Since they are recessed, they also do not provide the same delineation in wet conditions as the raised markers.

In Oregon, a significant contribution to the failure of reflective markers is studded tire wear. Recessed markers have been thought to last longer because of the additional protection the grooves provide. In actuality, this was not the case. Recessed markers were placed in the Bend area and, within three months, had lost all reflectivity due to damage caused by studded tires. The markers were removed and replaced with another brand of reflective marker, and within six months, the new markers needed to be replaced. As a result, these markers have been completely removed.

A cost analysis was performed to determine the equivalent uniform annual cost (EUAC) of applying each of the different pavement marking materials. Table 3 shows a summary of the equivalent uniform annual costs (1995 dollars) for each of the three alternative markings that were analyzed.

Table 3: Summary of Costs

ALTERNATIVE	LIFE	EUAC/mile
Paint	8 months	\$176
Raised Markers	2 years	\$436
Recessed Markers	3 years	\$539

Paint striping and raised markers are good alternatives for marking state highways. Paint has a minimal lifecycle cost with minimal traffic impacts during replacement. Skip lines enhanced by raised markers provide excellent lane delineation both visually and audibly. However, because the costs of raised markers are around \$250 more per year per mile than paint, they should only be used when it is cost effective or when needed to improve traffic safety. Also, the reflectivity of the markers may drop as much as 70% in the first year.

Skip lines enhanced by recessed markers cost approximately \$100 per year per mile more than skip lines enhanced by raised markers. This cost is based on a 3-year life for recessed markers, a 12-year analysis period, and a discount rate of 4%. Recessed markers also do not perform as well as raised markers. The initial performance is reduced strictly because they are recessed. The slots collect debris, rain, and snow and, when covered, are ineffective. Indications are that a maintenance program to remove the debris would not be viable. The conclusion was that “because of the expense and poor performance, recessed markers should not be used by ODOT.” Table 4 is adopted from this report and summarizes the recommendations made by the authors.

Table 4: Recommendations for ODOT

	SNOW ZONE (elev. >2,500')	NON-SNOW ZONE		
		<10,000 ADT ¹	10,000 - 30,000 ADT	>30,000 ADT
GOOD ALIGNMENT	PAINT	PAINT	RAISED/PAINT	RAISED
POOR ALIGNMENT²	PAINT	RAISED/PAINT	RAISED/PAINT	RAISED

¹ Raised markers should be considered for high seasonal traffic volumes and for heavy rain and fog zones.

² Consider durable markings for special applications.

These findings were corroborated by a study conducted by Endres¹² for Michigan DOT. He concluded that raised pavement markers outperform recessed markers in both dry and wet conditions.

2.3. Kentucky DOT – Evaluation of Snowplowable Markers

Kentucky DOT conducted two studies 31 years apart, in 1982¹³ and in 2013¹⁴. The objective of the 1982 study was to evaluate available snowplowable markers under similar traffic and snowplowing operations. The researchers studied the performance of recessed pavement markers during ice and snow conditions in Kentucky. They observed several problems associated with recessed markers, such as the collection of debris, rain, and snow in the recessed slots, which obstructs retroreflectivity, similar to the results seen in Oregon¹¹. They also observed that during the snow removal activities, the grooves retained snow and ice. This problem was short lived in areas that had moderate traffic volumes, because the snow melted and the water was whipped out by the moving vehicles. The remaining two-thirds of the marker was obscured due to water and debris. In conclusion, they stated that even though nighttime visibility was reduced, recessed pavement markers remained visible.

The following five different markers were tested: (1) Stimsonite 96; (2) Dura-Brite; (3) recessed; (4) Kingray; and (5) Prismo Roadstud. The Stimsonite 96, Dura-Brite, and recessed markers were found to be acceptable snowplowable markers. All three of these markers were found to have adequate reflectivity during both dry and wet nighttime conditions. Marker reflectivity was maintained over the test period, and the markers proved to be durable when subjected to snowplow operations. However, considering all available input, the recessed marker was recommended as the most functional and cost effective. The recessed marker that was included in this study used a regular raised marker placed in a groove. This installation involved placing a regular or low-profile raised marker into a groove cut into the pavement so the top of the marker was flush with the pavement surface. The Stimsonite 911 marker was installed in the groove.

Evaluation of the snowplow operations concluded that the Stimsonite 96, DuraBrite, and the recessed markers qualified as snowplowable markers. None of these three markers sustained any noticeable damage as a result of the limited number of snowplow operations. The Prismo marker was found not to be snowplowable. The Kingray markers sustained significant damage from the snowplow operations. As a result, the Stimsonite 96, DuraBrite, and recessed markers were considered as acceptable snowplowable markers. All three of these markers were found to have adequate reflectivity that was maintained over the test period and proved to be durable when subjected to snowplow operations. However, the recessed marker was recommended as the most functional and cost effective. This recommendation was based on the following characteristics of the recessed marker: (1) ease of installation; (2) high retention of reflectivity; (3) durability when subjected to snowplow operations; (4) relative cost of the marker and its installation; and (5) lack of interference with normal snowplow operations. Based on these results, it was recommended that both the Stimsonite 96 (steel casing) marker and the recessed marker design should be used.

From the earlier study conducted by the Kentucky DOT¹³ the Stimsonite 96 raised snowplowable marker was determined as the best option available. Due to problems experienced with these markers, the objective of the new study was to evaluate viable alternatives to these raised markers, as well as alternative methods and equipment for snowplowing roadways.

The Marker-One¹⁵ design was determined to be the best available alternative to the traditional steel casting snowplowable marker. An initial limited test was conducted with these markers placed in an eight-foot groove cut in the pavement, with one marker placed at the middle and one within one foot of the end of the groove. Marker performance was examined under different weather and light conditions. Over a period of two years, none of the markers was missing, water was found to drain from the groove quickly, and debris did not accumulate in the groove.

A larger-scale test installation was undertaken at two different U.S. highways, using the same design for the groove and installation of the markers. The markers remained effective during rainy conditions. Water accumulation in the groove was observed at flat or at hillcrest sections, with most of the time only one of the two marker lenses in the groove covered by water. Under heavy rain conditions, about 20% of the grooves had one marker still effective, while only 2% of the grooves had both markers covered by water. After one winter with limited snowplowing operations, only three of 1,850 lenses was missing. No damage to the pavement was noted as a result of the groove.

2.4. Maryland – Evaluation of Snowplowable Retroreflective RPMs

The Maryland State Highway Administration participated in the AASHTO National Transportation Product Evaluation Program (NTPEP) of Snowplowable Raised Pavement Markers (SRPM)²⁰. The participating manufacturers and products tested are listed in Table 5.

Table 5: Participating Manufacturers and Products in the Maryland SHA Study

Company Product	Trade Name	Product #
3M™ Company	3M™ Series 190 Marker	190-H960HP
Avery-Dennison Corp	Stimsonite®	Model 101
Avery-Dennison Corp.	Stimsonite®	Model 96
Hallen Products Ltd.	Ironstar	1W664
Astucia (UK), Ltd.	Astucia Intelligent Flush Stud	F-Series ND
Nightline Markers, Inc.	NightLine	B-400
Pac-Tec, Inc.	Rayolite® Snow-Lite	Model 100

Two sites with different pavement types, flexible pavement (hot mix asphalt, or HMA) and rigid pavement (Portland cement concrete, or PCC), were used for the field experiments. For each SRPM model, 40 units were installed in both the flexible pavement and rigid pavement sites. Installations were completed by the manufacturers. Both sites were fully access-controlled and did not require crack sealing or extensive patching during the evaluation period; had AADT over 20,000; were generally free of horizontal and vertical curves; and had a minimum average snowfall of 25 inches per year, controlled by a combination of plowing, salt, and a combination of deicing agents. Biannual SRPM field evaluations included inspection of SRPM housing and lens, retroreflectivity readings taken before and after cleaning, and nighttime visibility studies conducted during darkness at a distance of 122 meters (400 feet) using low-beam headlights.

Nighttime visibility remained high after the first six months for most reflectors. Only the Astucia Intelligent Flush Stud had a larger drop. Over the same period of time, hardened epoxy and damage caused by foreign objects had occurred in a limited number of cases and had no significant impact on the study results. Housings that were not flush with the road or were incorrectly installed showed a higher level of damage during field investigations of the raised pavement markers.

With respect to durability under snowplowing operations, during the period of the study, the winter was unusually warm and dry. To meet the required number of plow hits for one season, a vigorous plowing operation was completed in rainy conditions. This technique was considered to most closely resemble plowing in snowy conditions. Each marker received 24 hits, and all markers remained intact. The trucks were equipped with steel-bladed plows and were traveling at approximately 30 mph. There were no chemicals applied during this

operation. There were no additional plow hits made from actual snowplowing. There were 15 to 20 passes of deicing chemical application (on both test decks) at a different time.

2.5. Indiana – Effectiveness and Criteria for Placement of RPMs

Jiang authored a study for the Indiana DOT in 2006, *Effectiveness and Criteria for Placement of Raised Pavement Markers*.²¹ The Indiana DOT has been using RPMs on all interstate highways and multilane divided highways. However, RPMs are used on only a few of Indiana's two-lane highways, although they experience a relatively large number of fatal crashes. The effects of RPMs on roadway safety could be positive or negative, depending on the traffic conditions and geometric characteristics of the roadway.

To determine whether RPMs can improve safety on rural roads and to identify the roadway sections and curves for RPM installations to improve safety, the recommendation was to follow the *NCHRP Report 518* guidelines¹⁰. For this purpose, the following accident modification factor (AMF) was used:

$$AMF = \frac{\text{expected number of crashes with RPM}}{\text{expected number of crashes without RPM}}$$

Generally, raised pavement markers can improve highway safety when traffic volume is relatively high and the degree of curvature of the horizontal curve is low (i.e., the curve is gentle).

The adopted guidelines for raised pavement markers on two-lane roadways are as follows:

- AMFs should be used to guide decisions on where not to install raised pavement markers (i.e., when the AMF is greater than 1). An AMF less than 1 would indicate a positive safety effect (i.e., a reduction in crashes), while an AMF greater than 1 would indicate a negative safety effect (i.e., an increase in crashes).
- Given the negative safety impacts that are demonstrated to be associated with curves with more than 3.5 degrees of curvature, and given the findings of speed increases in association with raised pavement markers, it would seem prudent to avoid placing raised pavement markers well in advance of roadway sections with substandard geometry or where the feature is unexpected because of the character of the road previously encountered by the driver.
- An analytical engineering procedure should be undertaken at locations where the AMF is less than 1 to assess the cost-effectiveness of raised pavement marker installation.
- The results of the analytical engineering procedure should form part of the decision-making process for whether to install raised pavement markers at a given location. Issues to be considered with this information are:

- Other measures for improving nighttime crashes that may result in higher benefit-cost effectiveness.
- Other locations that may result in a higher-than-expected cost-effectiveness from the installation of raised pavement markers (thus, the results of the engineering study should be entered into the safety resource allocation process).

On four-lane roadways, the adopted guidelines for raised pavement markers are as follows:

- AMFs should be used to guide decisions on where to install raised pavement markers (i.e., when the AMF is less than 1).
- An analytical engineering procedure should be undertaken if a cost-effectiveness study is required.

2.6. Quebec – Pavement Marking Retroreflectivity in Cold Regions

Research on *Pavement Marking Retroreflectivity in Cold Regions*²² was undertaken to investigate retroreflectivity issues faced by MTQ (Ministère de Transports du Québec). The literature survey focused on the various pavement marking materials and on the causes and solutions for retroreflectivity degradation. Solutions included recessed pavement marking or adding raised reflective pavement markers (RRPMs).

The Canadian study identified the following factors as having an impact on pavement marking durability:

- Material type
- Location of marking line
- Traffic composition (proportion of trucks)
- Quality of construction
- Road/highway type
- Speed of traffic
- Age of pavement marking
- Annual average daily traffic (AADT)
- Weather conditions
- Surface pavement condition
- Snow removal operations

RRPMs and their snowplowable alternative, snowplowable reflective pavement markers (SRPMs), are solutions commonly used in addition to pavement markings to ensure visibility of markings in poor visibility and wet conditions. SRPMs can resist many winters and therefore are a solution to ensure retroreflectivity levels on roads. On the 3345 road miles surveyed in Kentucky¹⁴, an average of only 4.5% of SRPMs were missing. On newer or recently resurfaced roads, this average dropped to 0.4%. Factors that determine the

resistance of SRPMs were defined as their shape (which in turn influences the resistance of the SRPM to snowplow blades), the frequency of snow removal operations, the quality of installation, and the pavement condition.

Snowplow blades are most commonly made out of steel or carbide. These rigid blades can easily damage pavement marking materials. Some agencies have started using other types of blades to try to limit this damage. In a pilot project done in the state of Virginia²³, urethane was determined to cause less damage to pavement markings. Snowplow blades were also supported by small wheels to reduce the force applied on pavement markings.

A widely used solution to increase pavement marking durability is recessing it either in rectangular stripes or on rumble strips. Many studies have concluded on the efficiency of this practice. In Rhode Island, retroreflectivity losses after winter maintenance were 27% for recessed markings as compared to 45% for non-recessed markings. Recessed pavement markings were determined to have a service life twice as long as non-recessed markings and to cost less in the long run²⁴.

Several solutions to pavement marking durability and retroreflectivity issues have been identified in previous studies. Recessed pavement markings have proven to be a reliable method to protect pavement markings from snowplow wear. Applying markings on rumble strips seems to have similar results. Other studies show promising results when certain changes are applied to snowplows, such as changing blades to urethane or supporting the blades with wheels and therefore reducing friction between the blade and pavement markings. SRPMs have also proven to be a solution to ensure retroreflectivity levels, even when pavement markings become deficient.

2.7. AASHTO NTPEP

AASHTO maintains a National Transportation Product Evaluation Program (NTPEP)²⁵, which evaluates a variety of pavement marker materials. However, the current evaluations concentrate on raised plowable and non-plowable permanent pavement markers. There are no evaluations of recessed pavement markers.

2.8. Summary of Findings from Literature Review

Permanent raised and/or recessed pavement markers (PRPMs and RPMs) are delineation devices that are often used to improve preview distances and guidance for drivers in inclement weather and low-light conditions. The MUTCD specifies the conditions under which such markers can be used. A typical example is the following: “Retroreflective or internally illuminated raised pavement markers may be used as positioning guides with longitudinal line markings without necessarily conveying information to the road user about passing or lane-use restrictions. In such applications, markers may be positioned in line with

or immediately adjacent to a single line marking, or positioned between the two lines of a double center line or double lane line marking” (MUTCD, Ch. 3B, p. 379)¹.

Safety. The primary objective of such markers is to improve the safety of motorists during inclement and low-light conditions. Yet, some studies have suggested that under certain conditions, the application of such markers may cause an increase in accidents. *NCHRP Report 518*¹⁰ addresses this issue. The researchers developed analytical models to analyze the effects of such markers under a variety of conditions. In general, they concluded that “the installation of PRPMs at non-interchange locations on four-lane freeways showed neither a positive nor a negative overall safety effect on total and nighttime crashes. However, some significant reductions were recorded for wet weather crashes at those locations on four-lane freeways, and there are indications that PRPMs are only effective in reducing nighttime crashes where the AADT exceeds 20,000 veh/day.” Other researchers have also developed volume-based guidelines for the installation of markers (see below).

In the conclusions, the NCHRP researchers recommended adding to the MUTCD the following statement regarding the use of PRPMs on two-lane roadways and four-lane divided freeways: “Retroreflective raised pavement markers enhance guidance for drivers by providing longer delineation of the travel path during nighttime and wet pavement conditions. They also provide auditory feedback when the motorist approaches the edge of the travel lane, although snowplowable raised markers do so to a much lesser extent. These positive effects can be offset sometimes by inducing higher speeds, which under certain conditions, such as on sharp curves, can result in an overall negative safety benefit.”

The following paragraph was recommended under “Guidance” in the MUTCD: “The use of any raised pavement markers as a supplement or replacement to standard pavement markings should be based on an analytical engineering study of the potential safety impacts and costs.”

Recessed vs. raised markers. The issue of recessed vs. raised markers has been investigated by several states. Clearly, raised markers offer better visibility as well as auditory warning to the motorists. However, they become vulnerable under snowy conditions due to the detrimental effects of snowplowing operations. A variety of plowable raised markers have been developed with mixed success. Another alternative is to use recessed markers, which are located in slots beneath the road surface and thus presumably are less vulnerable to snowplowing. The evidence is, again, mixed: there is loss of reflectivity due to ice and debris collected in the slots. They are not completely immune to snowplowing operations and are costlier to install and maintain. Yet, several states and provinces are using them, in addition to the raised markers, notably: Kentucky, Oregon, and Quebec^{11, 13, 14, 22}.

Snowplowing. Snowplowing operations present a significant hazard to the durability of the markers, and several states have investigated alternative plowing mechanisms, e.g., steel blades vs. rubber-tipped blades, or blades on wheel rollers^{13, 14}.

New technology. New technology for markers has been adopted from airport runway operations, where LED (light-emitting diode)-powered markers have been extensively used. Manufacturers are now providing these types of markers as well.¹⁵

A listing of manufacturers approved by MassDOT, as well as other manufacturers, is included at the end of this review.

Table 6 lists the manufacturers and their products approved by MassDOT. 3M™ specifications¹⁵ for the 290 Series markers approved by MassDOT clearly state that the markers are effective for non-snowplow conditions. However, MassDOT bypasses this property of the 290 Series markers by installing them in recesses or slots on the highway. Ennis-Flint® and Rayolite®¹⁵ markers are raised snowplowable markers that are placed in recesses or slots within pavements and utilized as recessed pavement markers.

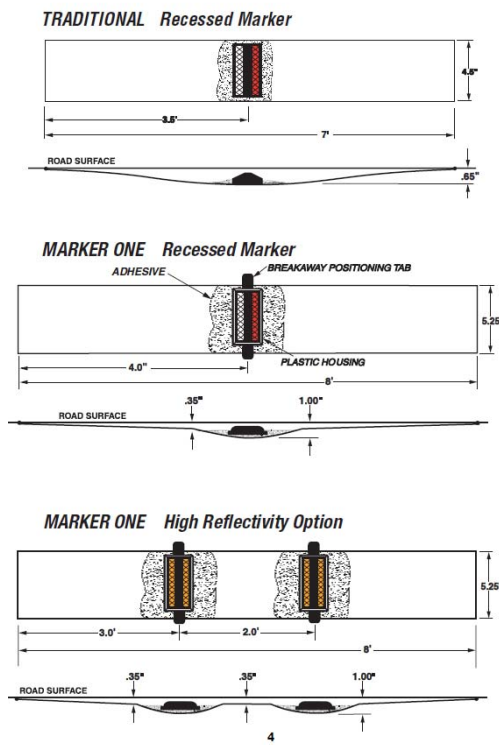
Table 6: Pavement Markers Currently Used by MassDOT

Standard Bid Item	Manufacturer	Product Name	Description	Qualification Date	Qualification Type	Remarks
864.31	3M	290-W	One-Way, White	Prior to 02/19/2010	Full	
864.32	3M	291-Y	One-Way, Yellow	Prior to 02/19/2010	Full	
864.33	3M	290-WR	Two-Way, White-Red	Prior to 02/19/2010	Full	
864.34	3M	291-YR	Two-Way, Yellow-Red	Prior to 02/19/2010	Full	
864.35	3M	291-2Y	Two-Way, Yellow-Yellow	Prior to 02/19/2010	Full	
864.31	Ennis-Flint	Stimsonite C80	One-Way, White	Prior to 02/19/2010	Full	
864.32	Ennis-Flint	Stimsonite C80	One-Way, Yellow	Prior to 02/19/2010	Full	
864.33	Ennis-Flint	Stimsonite C80	Two-Way, White-Red	Prior to 02/19/2010	Full	
864.34	Ennis-Flint	Stimsonite C80	Two-Way, Yellow-Red	Prior to 02/19/2010	Full	
864.35	Ennis-Flint	Stimsonite C80	Two-Way, Yellow-Yellow	Prior to 02/19/2010	Full	
864.31	Rayolite	Model 2004, Type G	One-Way, White	Prior to 02/19/2010	Full	
864.32	Rayolite	Model 2004, Type H	One-Way, Yellow	Prior to 02/19/2010	Full	
864.33	Rayolite	Model 2004, Type C	Two-Way, White-Red	Prior to 02/19/2010	Full	
864.34	Rayolite	Model 2004, Type X	Two-Way, Yellow-Red	Prior to 02/19/2010	Full	
864.35	Rayolite	Model 2004, Type D	Two-Way, Yellow-Yellow	Prior to 02/19/2010	Full	

***Source: MassDOT Qualified Slotted Pavement Markers²⁶**

Marker One¹⁵ claims that its product, the R-100, which uses traditional state-approved recessed snowplowable reflective markers bonded into tough plastic housings and installed in shallow recessed grooves, outperforms traditional recessed markers. Figure 6 delineates the difference between traditional pavement marker installations and R-100 installations.

Figure 6: Differences Between a Traditional Recessed Marker and R-100



The specifications of installing the R-100 Housing and Reflector are shown in Figure 7.

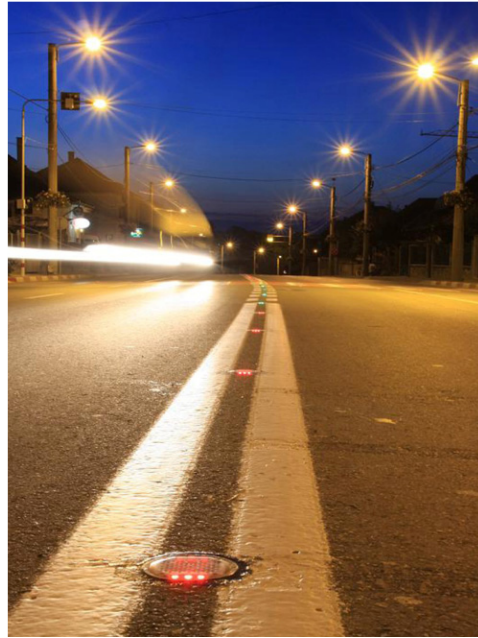
Figure 7: Specifications for R-100 Housing and Reflector

Specifications for R-100 Housing and Reflector	
MATERIAL:	Polycarbonate Plastic
WEIGHT:	Housing 2.00 oz. Reflector 2.00 oz.
HOUSING SIZE:	5.00" x 3.00" x .70" high
SPECIFIC INTENSITY cd/ft² OF REFLECTIVITY AT 0.2° OBSERVATION ANGLE	
WHITE:	3.0 at 0° entrance angle 1.2 at 20° entrance angle
YELLOW:	60% of white values
RED:	25% of white values

Solar LED pavement marker technology is the latest in pavement marker technology. They can be installed as recessed or raised markers. In the FHWA-published *Innovator Magazine*²⁷, Washington State has declared that it will be using LED recessed pavement

markers that prevent removal by snowplows. Figure 8 shows an example of the solar-powered recessed delineators in use.

Figure 8: Recessed Solar-Powered Lane Delineators to Avoid Removal by Snowplows



They maximize a driver's ability to maneuver dark patches, inclement weather, and slippery or icy conditions. Adopted from airport runways, this technology is now becoming more accessible due to the reduction in the cost of producing LEDs. According to Brighter World Lighting LLC¹⁵, its solar-powered LED markers have a resistance of up to 30 tons, illumination greater than 110 hours, and can be either adhered or anchored to the pavement. It claims that the self-illuminating character of these pavement markers provides advance hazard warnings to drivers. These markers are also highly reliable and easy to install.

Pavement marker technology has come a long way. This section summarizes the technology adopted so far, technology in use, and the future of pavement markers. The next task was conducting surveys at numerous state agencies to determine the current state of practice and analyzing these results to provide MassDOT with recommendations on the future of pavement markers.

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3.0 Research Methodology

The research methodology adopted in this synthesis report provides a critical review of current pavement marker installation practices adopted by various state DOTs in the United States and Canada. A survey among peer states was conducted for this purpose. A questionnaire on current pavement marker practices was distributed to the state agencies. The questionnaire requested information on types of pavement markers used by the state agency for lane delineation and requested feedback on their installation procedure, maintenance, and performance. The survey consisted of 18 questions. The survey focused on obtaining answers to questions such as type of pavement markers being used, model numbers, adhesion methods, installation procedure, maintenance, cost, and overall satisfaction of different pavement markers that were being used. Another question related to snowplowing techniques used by the different states. The questionnaire is included in Appendix 7.1.

Twenty-one DOTs and one Canadian province responded to the survey, including Alaska, Arkansas, Florida, Georgia, Idaho, Illinois, Indiana, Iowa, Louisiana, Maryland, Maine, Michigan, New Mexico, North Dakota, Ohio, South Carolina, Texas, Utah, Virginia, Wisconsin, Wyoming, and the province of Saskatchewan. These responses are summarized below.

Alaska

Alaska uses recessed snowplowable markers. However, the respondents skipped questions on practices and costs.

Arkansas

Arkansas uses temporary raised markers, non-snowplowable RPMs, and recessed snowplowable markers. The state is currently replacing all existing pavement markers with snowplowable markers with raised snowplowable markers. 3M™ 290 Series two-way markers are the preferred markers. The markers are attached to the pavement using bituminous adhesive. Pavement surface temperature, ambient temperature, pavement surface moisture, and pavement cleanliness are the quality control parameters monitored during installation. Maintenance is performed when needed, and existing snowplowable castings are checked annually for adhesion to pavement. Maintenance usually consists of replacing the pavement marker completely. Most pavement markers in the northern part of the state are damaged or removed during snowplowing operations in winter. On an average, it was reported that all pavement markers lasted over two years. About 50% reduction in reflectivity is observed in the markers over their life span. The approximate unit acquisition cost is \$0.75 per marker. The approximate installation cost, including labor costs/unit, is \$1.25 per marker. The approximate maintenance cost/unit is \$2.75. The type of snowplowing blades used is a carbide-tipped blade. The snowplowing technique uses pre-treatment with brine. Pavement markers are removed during plowing, and the agency considers this to be a major reason for failed pavement markers.

Florida

Tallahassee in Florida uses temporary raised markers and raised non-snowplowable markers. Manufacturers include 3M™, Ennis-Flint® and Rayolite®. A list of approved models is provided in Table 7.

Table 7: FDOT Approved Markers List

MODEL	SUPPLIER
3M™ 290 PSA Series	<u>3M™ Company</u>
APL Certification Number: 706-001-004,706-002-009	
Limitation: "Concrete use only"	
<u>3M™ 290 Series</u>	<u>3M™ Company</u>
APL Certification Number: 706-001-002,706-002-007	
<u>Apex™ Model 921</u>	<u>Apex™ Universal Inc.</u>
APL Certification Number: 706-001-008	
<u>Ennis-Flint® Model 80</u>	<u>Ennis-Flint® Paint, Inc. dba</u> <u>Ennis-Flint®</u>
APL Certification Number: 706-001-006	
<u>Ennis-Flint® Model 980</u>	<u>Ennis-Flint® Paint, Inc. dba</u> <u>Ennis-Flint®</u>
APL Certification Number: 706-001-013,706-002-011	
<u>Ennis-Flint® Model C80-FH</u>	<u>Ennis Paint, Inc. dba Ennis-Flint®</u>
APL Certification Number: 706-001-012,706-002-012	
<u>Rayolite® Round Shoulder</u>	<u>Pac-Tec Inc., Rayolite® Div.</u>
APL Certification Number: 706-001-009	
<u>Round Shoulder ARC FH</u>	<u>Pac-Tec Inc., Rayolite® Div.</u>
APL Certification Number: 706-001-014,706-002-010	

***Source: FDOT Approved Markers List²⁸**

Section 706 of the FDOT *Standards Specifications Handbook*²⁹ details the procedure adopted to adhere raised pavement markers to the pavement using a bituminous adhesive. Adhesive is heated to a temperature between 375°F and 425°F and applied directly to the bonding surface from the melter/applicator by either pumping or pouring. Application temperature has to be maintained between 375°F and 425°F. The adhesive may be reheated. All RPMs are installed with the reflective face of the RPM perpendicular to a line parallel to the roadway centerline. If more than 2% of the RPMs fail in adhesion or alignment within the first 45 days under traffic, all failed markers are replaced at no expense to the department. If more than 5% of the markers fail in adhesion and or alignment during the initial 45-day period, the engineer will extend the replacement period an additional 45 days from the date that all replacement markers have been installed. If, at the end of the additional 45-day period, more than 2% of all markers (initial installation and 45-day replacements combined) fail in adhesion or alignment, all failed markers are replaced at no expense to the department.

Index 17352 of the FDOT *Design Standards* book³⁰ suggests that RPMs shall be spaced at 40 feet on all skip lane lines and skip center lines. The spacing may be reduced to 20 feet if required. The spacing on solid lines and solid/skip combination lines has to be 40 feet. All RPMs are required to be offset 1 inch from solid longitudinal lines, and this spacing may be reduced on sharp curves. The markers are usually replaced after 24 months. The old markers are removed, and new markers are installed. About 10% of all installed markers failed before initial maintenance, and 35% reduced reflectivity was observed in the remaining markers. Loss of retroreflectivity is the major cause of failure of these markers. \$3.60 is the approximate installation cost per unit. Snowplowable practices are not applicable in Florida.

Georgia

Georgia uses temporary raised markers. The state specifies that it mainly uses raised pavement markers. The names of the manufacturers are Apex™, Ennis Paint Inc., Pexco® LLC, Rayolite®, and 3M™. The link to the model number for the markers is given in QPL 76 of “Raised Pavement Markers”³¹. The quality control parameters monitored during pavement marker installation are ambient temperature, pavement surface moisture, and pavement cleanliness.

Idaho

Idaho does not use retroreflective or internally illuminated pavement markers.

Illinois

Illinois uses temporary raised markers, raised snowplowable markers, and recessed snowplowable markers. The names of the manufacturers are Ennis-Flint®, Rayolite®, and 3M™. The information on model numbers for the approved markers is provided in Table 8.

Table 8: Illinois DOT Qualified Product List of Snowplowable Raised Pavement Markers

Manufacturer	Raised Reflective Pavement Marker Casting	Raised Reflective Pavement Marker Casting (Bridge)	Replacement Reflector
Ennis Traffic 6565 West Howard Niles, IL 60714 Contact: Pete McCafferty Phone: 630-841-4711 Email: petem@ennistraffic.com	Model 96LP Model 101LP	Model 96LPS Model 101LPS	Model 944 Model C40
Ray-O-Lite/Pac-Tec, Inc. 4500 N. Sam Houston Parkway W. Suite 120 Houston, TX 77086 Contact: Robert McCullohs Phone: 706-416-0042 Email: rmccullohs@rayolite.com	Hallen Ironstar Model 664H Hallen Model H960 Hallen Model H1010	Hallen Model H960B SnowLite Model 200 Hallen Model H1010B	Model 2004
Three M Three M Center Building 225-5S-08 St. Paul, MN 55144-1380 Phone: 1-800-553-1380 prompt # 1 Email: tnortheast@mmm.com			Model RPM-190

*Source: ILDOT QPL³²

The description of the following installation procedure of the pavement markers is from Section 781.03 of the 2012 ILDOT *Standard Specifications for Road and Bridge Construction*³³. The pavement is cut to match the bottom contour of the marker using a concrete saw fitted with 18- and 20-inch (450 and 500 mm) diameter blades. Diamond blades shall be used on Portland cement concrete pavement. The cut has to be clean and completely dry prior to pouring the epoxy. After the cut is cleaned, the configuration shall be checked using a pavement marker. The marker shall fit easily within the cut, with the leveling tabs resting on the pavement. If any force is required to place or remove the marker or if the leveling tabs do not rest on the pavement surface, the cut shall be enlarged as necessary. Installations on crowned pavements, super elevations, or ramps shall be cut deeper than those on level pavements if necessary to get proper marker fit. A rapid setting (hard in one hour) epoxy meeting the requirements of AASHTO M 237 is poured into the cut to within 3/8 inch (9 mm) of the pavement surface. The installed height for the reflective pavement markers should be approximately 0.3 inch (7.5 mm) above the road surface. Pavement and ambient temperature have to be maintained above 50°F at the time of installation for the epoxy to properly cure. A 97% efficiency of installed markers is required for completion of payment.

Indiana

Indiana uses raised snowplowable markers. The names of the manufacturers are Ennis Paint, Hallen Products Ltd., Nightline Markers, and Rayolite®. The model number for the approved markers is given in the Indiana DOT QPL³⁴. For installation procedure, see INDOT Standard Specifications, Section 808.11 for more details. The pavement or bridge deck surface shall be cleaned, RPM locations shall be accurately laid out and approved prior to installation, and RPM installation shall be in accordance with the manufacturer's recommendations. The installation slot shall be filled with sufficient adhesive to provide a watertight seal between the marker base and the pavement. If the pavement surface is new HMA, the pavement shall be cured for two days prior to installing the RPMs. The depth of the groove of installation is 1.64 inches for Type I Base and 1.51 inches for Type II Base. The type of adhesive is AASHTO M 237, type IV, Table 3. The quality control parameters monitored during pavement marker installation are ambient temperature, pavement surface moisture, and pavement cleanliness. The first maintenance occurs when lens (or casting) is first noticed as missing. The regular maintenance periods are determined by District RPM Maintenance Contracts, which typically run for two years. The major steps performed during maintenance are reflective lens and/or casting replacement. Approximately 25% of pavement markers have failed, been damaged, or gone missing. Of the remaining pavement markers, the percentage reduction in reflectivity is 25%. The major reasons for failure of pavement markers are due to snowplows. Snowplows are a major source of damage, cracking the reflective lenses and causing the castings to come loose. Pavement deterioration can also cause the castings to become loose. Approximate unit acquisition cost is \$80. Approximate installation cost, including labor costs per unit, is \$280. Approximate maintenance cost per unit is \$50. Approximate life span cost per unit is \$320. The type of snowplowing blade adopted is the steel carbide blade. The snowplowing technique adopted is salt spraying and plow speeds above 20 mph used on interstate highways. It is believed that plowing causes damage, according to the INDOT JTRP research report³⁵.

Iowa

Iowa does not use any type of retroreflective or internally illuminated pavement markers.

Louisiana

LA uses raised non-snowplowable markers. Ennis-Flint® models 911, 948, and C80 are used. Pac-Tech models Rayolite® 2002, ARC, and RSARC are used. 3M™ 290 and 291 series are used. Apex™ Model 921 is also being used by the agency. Installation involves standard surface-mount installation, using either standard bituminous adhesive (asphalt roadways only), polymer-modified bituminous adhesive (asphalt or concrete roadways), or epoxy (concrete roadways only). The most common installation procedure is using bituminous adhesive. Clean surface, blow dry immediately prior to marker placement, prepare and heat adhesive per manufacturer's recommendations, apply adhesive, and apply markers. Ambient temperature, pavement surface moisture, and pavement cleanliness are the quality control parameters monitored. From 12.5% to 20% of pavement markers fail, depending on whether the roadway is rural or urban. Of the remaining markers, they show a reduced reflectivity of 12.5% to 20% based on road type. Loss of retroreflectivity due to abrasion and cracking and loss of marker due to either improper marker adhesion to the adhesive or loss of adhesive bond to surface are the reasons for marker failure. The agency is satisfied with the performance of non-snowplowable markers.

Maine

Maine uses recessed snowplowable markers. However, additional information is unavailable, as the respondent did not answer the subsequent questions.

Maryland

Maryland uses temporary raised, raised non-snowplowable, and raised and recessed snowplowable markers. Hallen Products Ltd. and Ennis-Flint® supply recessed reflector lens. Snowplowable housings are supplied by Rayolite®, Hallen Products Ltd., and Ennis-Flint®. Snowplowable lenses are supplied by 3M™, Ennis-Flint®, and Hallen Products Ltd. Temporary pavement marker vendors include Pexco® Davidson Traffic Control, LLC, Ennis-Flint® Trading Co., and Rayolite® Company Div. of Pac-Tech Inc. Table 9 provides a summary of the most commonly used products.

Table 9: Maryland DOT Qualified Product List

PRODUCT	MANUFACTURER
Recessed Reflector Lens	Rayolite® Model #2002 (RPM (08-GA)-03)
	Stimsonite® Model 948
Snowplowable Housings	Ironstar 664 Housing
	Model H 1010 (RPM(04-OH)-04)
	Stimsonite® Model 101 LP (RPM(04-OH)-03)
	Stimsonite® Model 101 LPS
Snowplowable Lenses	Stimsonite® Model 96 (RPM(05-OH)-03)
	3M™ Series 190 Marker (RPM (05-0h)-02)
	Ennis-Flint® Model 944
	Rayolite® Model #2004 (RPM (05-OH)-02)
	Stimsonite® Model C40(D) (RPM (04-OH)-02)
Temporary Raised Pavement Markers	Stimsonite® Model C40(V) (RPM (05-OH)-02)
	35
	80F
	AA 9700 Series
	T.O.M.S.

*Source: Maryland DOT QPL⁴⁴

The installed height shall not exceed 0.25 inches above the road surface. The groove cut for the casting shall be the appropriate dimensions to allow 0.125 inches of movement side to side of the casting. The epoxy adhesive used to fasten the castings to the pavement surface shall conform to D 4383-05 Table X1.138. Recessed marker reflector lenses shall be installed in accordance with D 4383 (the top of the marker shall be 0.06 inches below the pavement surface) or as directed by the engineer. Epoxy Adhesive M237 Type II is used.

Pavement surface temperature, ambient temperature, depth of groove cut, pavement surface moisture, pavement cleanliness, and epoxy hardness are the quality control parameters monitored during installation. The first maintenance occurs during the first spring season after installation. Yearly observations are made, and markers are replaced at least twice during a one-year period. Major steps involved in maintenance include checking for adhesion and cracks in epoxy, removing loose RPMs, and filling in areas from removed or missing RPMs. Present research is pointing to areas of HMA roadway deterioration. Based on the stressed areas noted in the HMA around the markings and the epoxy adhesive is not present when pop-outs are noted. This theory has been supported by low to no failures in the PCC other than the usual two-year reflective lifecycle for lenses.

Approx. unit acquisition cost = \$7.10–\$7.50

Approx. installation cost, including labor costs per unit = \$38.00

Approx. maintenance cost per unit = \$1.20 unit for lens; total installed = \$9.00

Approx. life span cost per unit = \$65.00.

Snowplowing blades used by Maryland include carbon metal blades. Pavement is also pre-treated with brine. SRPMs are dislodged due to snowplows and become projectiles. The

Maryland DOT has demonstrated satisfaction with the performance of SRPMs. Presently, Maryland State Highway Administration is investigating alternative pavement markers like plastic housing with lenses and pavement markings that have wet reflective properties that can work in a groove situation.

Michigan

Michigan uses temporary raised markers. The names of the manufacturers are Apex™ Universal, Inc., Bunzl Extrusions/Davidson Traffic Control Prod, and Stimsonite® Corporation. The link to the model number for the markers is given in Section 022.06B of the Michigan DOT QPL on page 91³⁶. Per Michigan's Standard Specifications for Construction, temporary raised pavement markers are installed "using the manufacturer's recommended adhesive and in accordance with the manufacturer's instructions." Details about the manner of installation are not available. As for quality control, it is stated that pavement markers are only used for temporary traffic control applications. Maintenance may occur if markers are damaged or missing while still in use. Temporary pavement markers may fail due to damage from traffic and construction equipment, or due to improper installation.

When RPMs in permanent installations are used, the major failures were due to snowplow damage (and to a lesser extent, general traffic damage). Crystal loss or breakage also occurred, and over time, the castings would work free of the pavement. The average bid price for unit and installation was \$1.70. Michigan's snowplowing trucks have underbelly blades. Some are also equipped with front-mounted blades. A combination of plowing and salt is used for snow removal operations. Michigan used to use SRPMs. Even so, the repeated strikes from the plow blades in winter seemed to contribute over time to crystal breakage and loss, and the castings loosening from the pavement. Michigan DOT used to install SRPMs on its routes; however, this practice was discontinued a number of years back. There were many instances of the metal castings working free of the pavement over time, and in some cases becoming projectiles after being struck by either a snowplow or mower. The time and expense to maintain the RPMs to repair crystals and ensure the castings remained in place were too high, so their use was discontinued. Michigan is currently testing temporary LED solar RPMs.

New Mexico

New Mexico uses raised non-snowplowable and recessed snowplowable markers. Approved manufacturers include 3M™ and Ennis-Flint® in the approved product list for New Mexico. The depth of installation for both raised and recessed markers is 3/8 inch. Pavement surface temperature, moisture, depth of groove cut, and ambient temperature are the quality control parameters monitored. Snowplow information was not provided. The agency suggested moderate satisfaction with the markers being used.

North Dakota

North Dakota does not use retroreflective or internally illuminated pavement markers

Ohio

Ohio uses temporary raised markers and raised snowplowable markers. The names of the manufacturers are Ennis-Flint® and Hallen Products Ltd. Model numbers for the castings and reflectors are provided in Tables 10 and 11.

Table 10: Ohio DOT RPM Castings Qualified Product List

Sample Id	PS CD	Mtl Cd	Mtl Name	Brand Name	P/S Name	Street	City	St/Zip	Phone
QPLITEMS131G081530	96068-01	40401	RAISED PAVEMENT MARKER CASTING	STIMSONITE 101LP	ENNIS-FLINT	6565 W. HOWARD ST	NILES	IL 60714	847-647-4814
QPLITEMS001937	96068-01	40401	RAISED PAVEMENT MARKER CASTING	STIMSONITE 96LP	ENNIS-FLINT	6565 W. HOWARD ST	NILES	IL 60714	847-647-4814
QPLITEMS124C110654	95963-01	40401	RAISED PAVEMENT MARKER CASTING	H-1010	HALLEN PROD	4500 N. SAM HOUSTON PARKWAY WEST	HOUSTON	TX 77086	800-848-7025
QPLITEMS001689	95963-01	40401	RAISED PAVEMENT MARKER CASTING	H-960	HALLEN PROD	4500 N. SAM HOUSTON PARKWAY WEST	HOUSTON	TX 77086	800-848-7025

*Source: Ohio DOT QPL³⁷

Table 11: Ohio DOT RPM Reflectors Qualified Product List

Sample Id	PS CD	Mtl Cd	Mtl Name	Brand Name	P/S Name	Street	City	St/Zip	Phone
QPLITEMS000024	00511-01	40402	RAISED PAVEMENT MARKER REFLECTOR, 721.02	MARKER SERIES 190	3M TRAF. & VEH	3M CENTER, BLD 225-05S-08	ST. PAUL	MN 55144	651-736-0166
QPLITEMS001935	96068-01	40402	RAISED PAVEMENT MARKER REFLECTOR, 721.02	MODEL C40	ENNIS-FLINT	6565 W. HOWARD ST	NILES	IL 60714	847-647-4814
QPLITEMS001535	95642-01	40402	RAISED PAVEMENT MARKER REFLECTOR, 721.02	RAY-O-LITE 2004	PAC-TEC INC.	4500 N. SAM HOUSTON PARKWAY WEST	HOUSTON	TX 77086	800-848-7025

*Source: Ohio DOT QPL³⁷

The installation procedure of RPMs practiced by Ohio DOT is given in Traffic Engineering Manual Section 350 for Installation⁴⁰. The list of approved adhesives is shown in Table 12.

Table 12: Ohio DOT List of Approved Adhesives

Sample Id	PS CD	Mtl Cd	Mtl Name	Brand Name	P/S Name	Street	City	St/Zip	Phone
QPLITEMS10B5085048	09872-01	40403	RAISED PAVEMENT MARKER CASTING ADHESIVE	45W-D001&95A-D001	AEXCEL CORP	7373 PRODUCTION DR	MENTOR	OH 44060	440-974-3800
QPLITEMS000017	00506-01	40403	RAISED PAVEMENT MARKER CASTING ADHESIVE	EPOPLEX MA50	EPOPLEX/NJ	ONE PARK AVENUE	MAPLE SHADE	NJ 08052	800-822-6920
QPLITEMS10BG102947	06536-01	40403	RAISED PAVEMENT MARKER CASTING ADHESIVE	Mark 29.4	POLY-CARB	1881 WEST OAK PARKWAY	MARITTA	GA 44139	478-836-3011
QPLITEMS10BG103235	06536-01	40403	RAISED PAVEMENT MARKER CASTING ADHESIVE	MARK 29.5	POLY-CARB	1881 WEST OAK PARKWAY	MARITTA	GA 44139	478-836-3011
QPLITEMS000428	06536-01	40403	RAISED PAVEMENT MARKER CASTING ADHESIVE	MARK-29.9	POLY-CARB	1881 WEST OAK PARKWAY	MARITTA	GA 44139	478-836-3011
QPLITEMS000429	06536-01	40403	RAISED PAVEMENT MARKER CASTING ADHESIVE	MARK 29 COMP EPOXY	POLY-CARB	1881 WEST OAK PARKWAY	MARITTA	GA 44139	478-836-3011

*Source: Ohio DOT QPL³⁷

The quality control parameters monitored during installation are pavement surface temperature, ambient temperature, depth of groove cut, pavement surface moisture, pavement cleanliness, and epoxy hardness. RPM castings last for the life of the pavement. RPM reflectors are replaced every three years. Inspection and replacement of broken casting and reflectors are major steps during maintenance. Less than 1% of pavement markers have failed, been damaged, or gone missing. Reflectors are replaced every three years. They are mostly in good shape. The major reasons for failure of pavement markers are older pavements, snowplows, and poor installation. The approximate unit acquisition cost is \$20

installed, which includes RPM casting, cost of reflector, and installation. The approximate installation cost, including labor costs, per unit is \$10. The approximate maintenance cost per unit for reflector replacement is \$2.80 per RPM reflector. The approximate lifespan cost per unit is reflector, 3 years, plus casting for the life of pavement (about 10 to 12 years). Salt is used as part of the snowplowing. Snowplows damage reflectors and castings, too.

South Carolina

South Carolina uses temporary raised markers, raised non-snowplowable markers, and recessed snowplowable markers. The names of the manufacturers are Ennis Paint, 3M™, and Rayolite®. For installation procedure, surface-mounted raised markers are installed on all interstate highways and other federal aid roads having an AADT of greater than 500. Old markers are removed when the new markers are placed. Most are placed using bituminous adhesive. The depth of the groove of installation is 1/2 to 3/4 of an inch, with shape as recommended by manufacturer. The type of adhesive is epoxy.

The quality control parameter monitored during pavement marker installation is pavement surface temperature. The regular maintenance periods are three years for non-interstate routes and two years for interstate routes. Approximate installation cost, including labor costs per unit, is \$2.50. Approximate maintenance cost per unit is \$50. Approximate life span cost per unit is \$320. The type of snowplowing blades adopted is steel blades on plows and motor graders. The snowplowing technique adopted is pretreating with salt or brine if possible, then physical plowing if needed. Snowplowing typically removes the surface-mounted markers.

Texas

Texas uses raised non-snowplowable markers and recessed snowplowable markers. The approved manufacturers are shown in Table 13.

Table 13: Texas DOT Qualified Product List

Pavement Markers, (Snowplowable)	
Manufacturer / Distributor	Brand Name / Model / No.
4-H Supply, Inc.	Nightline A250 with reflective insert
Ray-O-Lite/Hallen Products Limited	H960 with 190 reflective insert
Pac-Tec, Inc. / Ray-O-Lite Division	Pac-Tec 300 with 2004 reflective insert
Ennis	C-40
3M Company	190 reflective insert

***Source: Texas DOT QPL⁴¹**

The *TxDOT Spec*⁴² Spec Item number for “raised pavement markers” is Item 672. Most markers are typically installed in a moving operation, where the contractor places the marker on a splat of adhesive. RPMs are typically placed by hand. TxDOT requires a 30-day performance period for all marker installations. Approximately 2 inches of groove is required to be cut in the pavement for installation. Epoxy adhesive is used. The first maintenance occurs typically after three years. About 10% of the markers fail before the end of the first year. Of the remaining, about 50% demonstrate reduction in reflectivity with one

year. Body damage to markers due to traffic is cited as the major cause of pavement marker failure. Approximate installation cost is \$2.89 each, and the state average bid price for a snowplowable marker is \$33.61 per marker. Texas uses a combination of steel and carbide blades for snowplowing alongside brine. The blades will remove over 70% of raised markers during the first snow/ice event. The plow does not even have to contact the marker; shifting ice will remove the RPM. The blades will grind or slice off the thermoplastic pavement markings. (This is more of a problem on concrete than on bituminous pavements). The temperature and the impact also seem to break up the pavement markers. Plowable markers hold up fairly well in concrete pavements. TxDOT seems to demonstrate a moderate satisfaction rating for the markers being used.

Utah

Utah uses recessed snowplowable markers. The name of the manufacturer is Ennis-Flint® (Stimsonite®). The model number of the marker is C80FH. Utah has just installed a field trial according to AZ DOT's standard as shown in the the Texas DOT QPL⁴¹.

The depth of the groove is 13/16 inch, and the type of adhesive is Crafcoc Hot-Applied Flexible Pavement Marking Adhesive. The quality control parameters monitored during pavement installation are pavement surface temperature, ambient temperature, depth of groove cut, pavement surface moisture, pavement cleanliness, pavement subsurface moisture, and alignment of groove cut.

The first maintenance occurs in three to five years if implemented after the trial. The major steps during maintenance are pending. Pavement markers were just installed this summer. The anticipated reasons for failure are lack of adhesion of marker to the road, or the reflective lens is missing or defective. The approximate installation cost, including labor costs per unit, for the field trial was \$10.55 each, not including \$21,000 mobilization based on about 3,900 markers. The type of snowplowing blades used are Joma blades. Utah has a "bare pavement" policy, which damages pavement markers. It uses salt and salt brine. With the markers being recessed, theoretically they shouldn't be damaged by the plows.

Virginia

Virginia uses temporary raised, raised non-snowplowable, and raised and recessed snowplowable markers. It also recommends Rayolite®, Ennis-Flint®, Accent Stripe, 3M™, Pexco®, Hallen Products Ltd. and Nightline as the manufacturers. Temporary or surface-mount markers are glued to the roadway with an adhesive. Snowplowable markers are installed in grooves, in a casting with epoxy. About a 2-inch groove is cut into the surface for installation. Depth of groove cut, pavement surface moisture, cleanliness, and epoxy hardness are the parameters monitored.

The first maintenance usually occurs about two to three years after installation. Maintenance is performed by visual inspection as needed and replacement of damaged parts. Approximately 25% of markers fail within the first year. Of the remaining, 50% demonstrate reduced reflectivity. Improper installation practices and damaged roads are responsible for the failure of the markers. Approximate procurement, installation, and labor cost add up to \$15 per marker. Snowplow practices include deicing chemicals and steel or carbide-tipped

snowplows. They are also considered as a major factor for pavement marker failure. The DOT demonstrated a good to satisfactory rating for the 2 x 4-inch lens installed in beveled cuts.

Wisconsin

Wisconsin uses temporary raised markers only. Apex™ 921 series, Stimsonite®, Ennis-Flint®, 3M™ 290 and 291 series, Round Shoulder 8800 Series, AA 9700 Series, and Rayolite® are the preferred manufacturers. Installation specifications are as per the manufacturer's instructions. The cost of procuring and installing a temporary pavement marker is \$4. Since Wisconsin does not use temporary markers in winter snowplowing, procedures are irrelevant for deciding the lifespan of the marker.

Wyoming

Wyoming does not use retroreflective or internally illuminated pavement markers.

Saskatchewan province, Canada

The province of Saskatchewan uses raised snowplowable markers and temporary raised markers. The name of the marker manufacturer is not specified. When lane lines are obliterated by construction or maintenance operations, center placement of markers (in direction of chainage) is practiced. Where passing is permitted in both directions, yellow markers are placed at the beginning of every third skip line (37.5 m). Where passing is prohibited in one or both directions, yellow markers are placed at the beginning of every second skip line or at intervals of 25.0 m. The beginning and the ending of No-Passing zones are marked on the appropriate side of the center line with white markers. Edge line and lane line placement of markers is carried out where required (in direction of chainage). Edge lines on tangent sections are marked at 100 m intervals with white markers. Edge lines on curves at transition points are marked at 40 m intervals. Lane lines are marked at 37.5 m intervals, every third skip line, on tangent sections, except on flared, bypass, and channelized intersections, where they are placed at 25.0 m intervals, i.e. every second skip line. Depth of the groove is not used by the Saskatchewan Ministry of Highways and Infrastructure. First maintenance occurs only for temporary markers.

Summary

This section summarizes survey responses. Twenty-two responses were obtained. However, it is inconclusive whether recessed snowplowable pavement markers perform better than raised snowplowable pavement markers. Agencies such as Maryland and Virginia demonstrated a high satisfaction rate with recessed markers. Agencies such as Oregon, Washington State, and Michigan are shying away from raised snowplowable markers and are exploring alternative technologies, such as solar-powered LED markers.

Plowing of snow, rain, and debris are major issues encountered by recessed pavement markers that defeat their purpose of visibility during inclement weather and poor light conditions. Raised snowplowable pavement markers tend to dislodge from the pavement during snowplowing operations and become projectiles which may lead to unsafe driving conditions. Several states (such as Utah) are currently conducting field trials of recessed

markers, and it was impossible to obtain their experience with recessed markers during the course of this survey.

4.0 Results

Twenty-two responses were obtained from the peer states survey. The states of Alaska, Arkansas, Florida, Georgia, Idaho, Illinois, Indiana, Iowa, Louisiana, Maryland, Maine Michigan, New Mexico, North Dakota, Ohio, South Carolina, Texas, Utah, Virginia Wisconsin, Wyoming, and the province of Saskatchewan in Canada responded to the survey. Twelve agencies use temporary raised markers. Nine agencies use raised snowplowable pavement markers. Five agencies use raised non-snowplowable markers. Nine agencies use recessed snowplowable markers. Two agencies are experimenting with solar-powered LED markers. Finally, four agencies do not use pavement markers at all for roadway delineation. It is important to note that state agencies resort to a combination of the above-mentioned pavement markers depending on the situation, weather conditions, and availability of financial resources. This can be better visualized by Figure 9.

Figure 9: Pavement Marker Types Being Used by Various Peer State Agencies

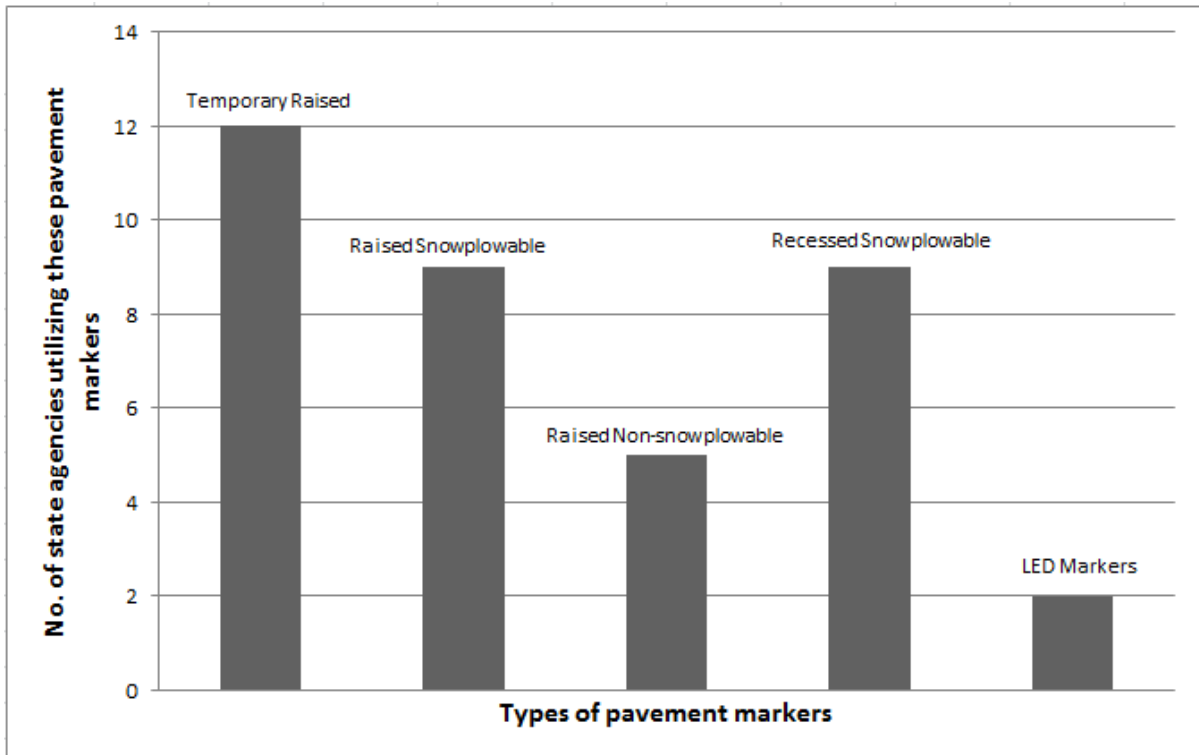
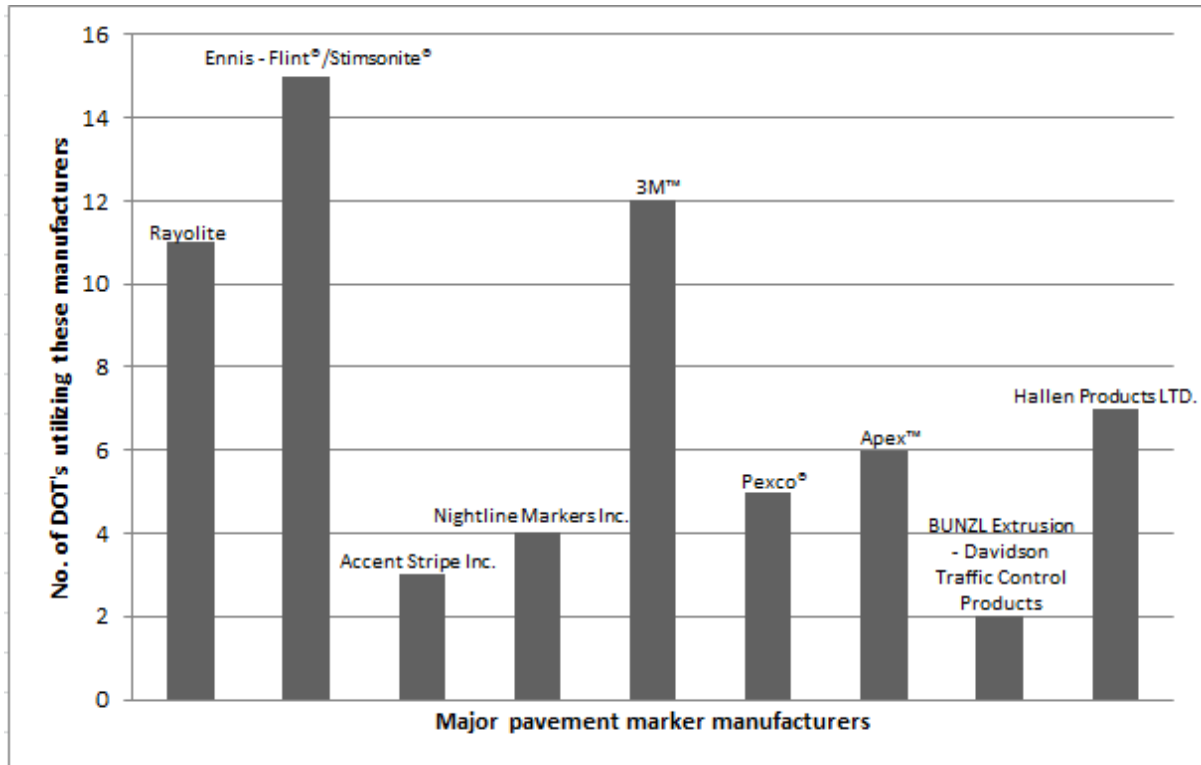


Figure 10 shows the major manufacturers featured in the qualified product lists (QPL) and the number of DOTs that feature them in their QPLs. Of the 22 survey respondents, 15 state agencies reported utilizing Ennis-Flint®/Stimsonite® as their preferred manufacturer, followed by 3M™ and Rayolite®. Hallen Products Ltd., Apex™, Pexco®, Accent Stripe Inc. and BUNZL Extrusions-Davidson Traffic Control Products are some of the other manufacturers that are present in several qualified product lists of DOTs. MassDOT uses three of these major manufacturers listed below.

Figure 10: Major Pavement Marker Manufacturers Featured in QPLs of DOTs



Costs associated with various pavement marker types are summarized in Table 14. Wherever information was not secured, the cell has been marked as unavailable.

Table 14: Costs Associated with Pavement Markers

State agency	Pavement marker type	Unit acquisition cost	Installation cost including labor costs/unit	Maintenance cost/unit	Life span cost/unit
Maryland	SRPM/Recessed	\$7.10– \$7.50	\$38.00	\$10.20	\$65.00
Wisconsin	Temporary Raised	Unavailable	\$1.00	\$3.00	Unavailable
Utah	Recessed	Unavailable	\$10.55	Unavailable	Unavailable
Arkansas	Temporary Raised	\$0.75	\$1.25	\$2.75	Unavailable
Ohio	SRPM	\$20.00	\$10.00	\$2.80	\$40.00
Indiana	SRPM	\$80.00	\$280	\$50.00	\$320.00
Virginia	RPM/SRPM/Recessed	\$15.00	Unavailable	Unavailable	Unavailable
Michigan	Temporary Raised	\$2.00	Unavailable	Unavailable	Unavailable
Texas	Temporary Raised/SRPM	\$2.89– \$33.61	Unavailable	Unavailable	Unavailable
Florida	Temporary Raised	\$3.60	Unavailable	Unavailable	Unavailable
South Carolina	Temporary Raised	Unavailable	\$2.50	Unavailable	Unavailable
*All costs are approximate					
*SRPM: Snowplowable Raised Pavement Marker					
*RPM: Non-snowplowable Raised Pavement Marker					

This section delineates the salient results obtained from the peer states survey on pavement marker practices. Nine agencies use recessed snowplowable markers. These include Alaska, Arkansas, Illinois, Maryland, Maine, New Mexico, South Carolina, Utah, and Virginia. However, based on the survey responses alone, it is inconclusive whether recessed, snowplowable markers outperform raised snowplowable markers.

Hence, a follow-up study is recommended in the future that would account for the experiences of the states that are currently conducting a field trial with recessed snowplowable markers.

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5.0 Conclusions

Retroreflective raised pavement markers enhance guidance for drivers by providing longer delineation of the travel path during nighttime and wet pavement conditions. They also provide auditory feedback when the motorist approaches the edge of the travel lane, although snowplowable raised markers do so to a much lesser extent. These positive effects can be offset by inducing higher driving speeds, which under certain conditions, such as on sharp curves, can result in an overall negative safety benefit.

The issue of recessed vs. raised markers has been investigated by several states. Clearly, raised markers offer better visibility, as well as auditory warning to the motorists. However, they become vulnerable under snowy conditions due to the detrimental effects of the plowing operations. A variety of snowplowable raised markers have been developed, with mixed success. Another alternative is to use recessed markers, which are located in slots beneath the road surface and thus presumably are less vulnerable to snowplowing. The evidence indicates the possible loss of reflectivity of recessed markers due to ice and debris collected in the slots. Recessed markers are also not completely immune to the plowing operations and are costlier to install and maintain. Yet, several states and provinces are using them, in addition to the raised markers, notably Kentucky, Oregon, and Quebec^{11, 13, 14, 18}.

Snowplowing operations present a significant hazard to the durability of the markers, and several states have investigated alternative plowing mechanisms, e.g., steel blades vs. rubber-tipped blades, or blades on wheel rollers^{13, 15}.

New technology for markers has been adopted from airport runway operations, where LED (light-emitting diode)-powered markers have been extensively used. Manufacturers are now providing these types of markers as well¹⁵.

A survey was conducted among peer states and provinces in the United States and Canada. The respondents answered questions pertaining to reflectorized marker installation practices, effectiveness of these markers, and satisfaction with the current pavement marker technology being used. All responses were summarized. A summary of their responses is shown in Table 15.

The states of Illinois, Indiana, Ohio, Texas, Arkansas, Maryland, Louisiana, New Mexico, and Virginia reported the use of snowplowable raised pavement markers (SRPMs). Some states are not completely satisfied and are seeking alternate technologies. Several agencies attribute pavement marker failure to snowplowing practices and are looking for alternative snowplow blades that cause less damage.

State agencies that have installed recessed pavement markers include Alaska, Illinois, Maine, South Carolina, Arkansas, Utah, Maryland, New Mexico, Virginia, Kansas, Oregon, West Virginia, and Pennsylvania. Among these states, Alaska, Illinois, Maine, South Carolina, Arkansas, Utah, Maryland, New Mexico, and Virginia responded to the survey. Most of these states are conducting ongoing trials of recessed markers. Maryland and Virginia were

the only two states that demonstrated a high satisfaction rate with recessed snowplowable markers. The authors recommend that MassDOT follow up with those state agencies that use snowplowable recessed markers, acquire the results from their recessed pavement marker trials, and investigate the applicability to Massachusetts conditions.

The authors also encourage MassDOT to investigate technologies of the future, such as LED markers and solar-powered LED markers, which would benefit the agency in the long run. These markers are self-luminous, lightweight, and easy to install. They can be anchored or adhered to the pavement and are relatively easy to replace. Since no slots are required for installation, water, snow, and debris do not pool around these markers. Additionally, as they are self-luminous, their visibility is high. Washington State has begun a test run with these markers. LED marker technology has proven to be very effective on airport runways, and the authors recommend that MassDOT consider LED markers as a serious contender for delineating Massachusetts roadways.

Table 15: Summary of Peer States Survey

Agency	TR	SRPM	RPM	Recessed	Adhesive	Remarks
Alaska	x	x	x	√	Unavailable	Installation information unavailable.
North Dakota	x	x	x	x	N/A	Does not use retroreflective or internally illuminating markers.
Illinois	√	√	x	√	AASHTO M37 compliant epoxy	Installation according to section 781.03 of the 2012 ILDOT <i>Standard Specifications for Road and Bridge Construction</i> .
Georgia	√	x	x	x	Unavailable	Uses temporary pavement markers only.
Michigan	√	x	x	x	Manufacturer's specification	Temporary markers only. Discontinued SRPMs due to iron casting shoes being projectiles during snowplowing operations. Currently experimenting with LED markers.
Maine	x	x	x	√	Unavailable	Installation information unavailable.
Idaho	x	x	x	x	N/A	Does not use retroreflective or internally illuminating markers.
Indiana		√			AASHTO M37 complaint	Installation specs. can be found in INDOT <i>Standard Specifications</i> , Section 808.11. It also uses partially recessed markers. The state is experimenting with rubber blades for snowplowing operations.
South Carolina	√	x	√	√	Bituminous or epoxy adhesive	For installation procedure, surface mounted raised markers are installed on all interstate highways and other federal aid roads having an AADT of greater than 500. The depth of the groove of installation is 1/2 to 3/4 of an inch, with shape as recommended by manufacturer.
Wyoming	x	x	x	x	N/A	Does not use retroreflective or internally illuminating markers.
Ohio	√	√	x	x	Epoxy	Snow plowing damages reflectors
Texas		√	√		Epoxy	Highly satisfied
Arkansas	√	√	x	√		Snowplowable castings are removed. No further details provided.

Agency	TR	SRPM	RPM	Recessed	Adhesive	Remarks
Canada (Saskatchewan)	√	x	x	x	N/A	Uses temporary pavement markers only.
Iowa	x	x	x	x	N/A	Does not use retroreflective or internally illuminating markers.
Utah	x	x	x	√	CRAFCO Hot-Applied Flexible Pavement Marking Adhesive	Recessed markers are being installed on a trial basis according to AZ DOT's standard. Information regarding maintenance costs, life span costs is unavailable. Strongly recommend follow up to discuss experience with recessed markers. The depth of the groove is 13/16 of an inch.
Florida	√	x	√	x	Bituminous adhesive	Section 706 of FDOT <i>Standard Specifications Handbook</i> delineates installation procedure.
Maryland	√	√	√	√	Epoxy M237 Type II	Recessed marker reflector lenses are installed in accordance with D 4383 (the top of the marker is 0.06 in. below the pavement surface) or as directed by the engineer. Recessed markers perform better on PCC than on HMA. Highly satisfied with recessed markers.
Wisconsin	√	x	x	x	N/A	Uses temporary pavement markers only.
Louisiana	x	√	x	x	Bituminous(asphalt); epoxy(PCC)	No snowplowable markers used.
New Mexico		√	x	√	unclear	Depth of installation for both raised and recessed markers is 3/8 in. Moderate satisfaction with recessed markers
Virginia	√	√	√	√	Epoxy AASHTO – M 237 type II	Recessed marker reflector lenses are installed in accordance with D 4383 (the top of the marker is 0.06 in. below the pavement surface) or as directed by the engineer. Recessed markers perform better on PCC than on HMA. Highly satisfied with recessed markers.

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7.0 Appendix

7.1 Survey Questionnaire

Introduction

The University of Massachusetts Lowell (UMass Lowell) under contract with Massachusetts Department of Transportation (MassDOT) is conducting a synthesis study ISA #72854 investigating the performance of reflectorized pavement markers across various states and provinces.

The overall objective of this research is to provide MassDOT with a pavement marker solution that maximizes safety, performance and length of service while minimizing lifecycle costs. One of the project tasks is to collect and review information from peer states and agencies relevant to the state of practice adopted by them for choosing and installing pavement markers.

There are 17 questions in this survey. You may edit your response at any point. Your responses will be submitted once you select the “Done” button at the bottom of Question #17.

However, if your response to Question #2 is “None”, you will not need to go any further.

Thank you for your participation. Your feedback is important and appreciated.

Question 1

Contact Information

1. Please enter your contact information

Name	<input type="text"/>
Agency	<input type="text"/>
Address	<input type="text"/>
Address 2	<input type="text"/>
City/Town	<input type="text"/>
State/Province	<input type="text" value="-- select state --"/>
ZIP/Postal Code	<input type="text"/>
Country	<input type="text"/>
Email Address	<input type="text"/>
Phone Number	<input type="text"/>

Question 2

Type of Retro-Reflective or Internally Illuminated Pavement Markers

2. Please select the type of retro-reflective or internally illuminated pavement markers (if any) being used by your agency for pavement delineation.

- Temporary Raised Markers
- Raised, Non-Snowplowable Markers
- Raised, Snowplowable Markers
- Recessed, Snowplowable Markers
- None

Other (please specify)

Questions 3 & 4

Details - Pavement Markings

Please provide the following details regarding the pavement markers currently being used by your agency.

3. Name of the Manufacturer(s):

4. Model Numbers for the approved markers. [Please insert a link to the list of approved markers if available].

Question 5

5. Briefly describe the installation procedure adopted by the agency for installing pavement markers.



Question 6

Details - Pavement Markings

6. Please describe the manner in which raised snowplowable markers are installed.

Depth of the groove

Type of adhesive

Other (please specify)

Question 7

Details - Pavement Markings

7. Please describe the manner in which recessed snowplowable markers are installed.

Depth of the groove

Type of adhesive

Other (please specify)

Question 8

Quality Control -Pavement Markings

8. Please select the quality control parameters monitored by your agency during pavement marker installation.

- Pavement Surface Temperature
- Ambient Temperature
- Depth of Groove Cut
- Pavement Surface Moisture
- Pavement Cleanliness
- Epoxy Hardness
- None

Other (please specify)

Question 9

Maintenance - Pavement Markings

9. Please answer the following pavement marker maintenance questions

When will the first maintenance occur?

What are the regular maintenance periods?

What are the major steps performed during maintenance?

Additional comments (if any)

Question 10

One Year - Pavement Markings

10. One year following installation:

What percentage of pavement markers has failed? (damaged or missing) -Percentage Failed (Approx.)

Of the remaining pavement markers, estimate the percentage reduction in reflectivity. Percentage Reduced Reflectivity (Approx.)

Question 11

Failures- Pavement Markings

11. Please describe what are the major reasons for failure of pavement markers



Question 12

Cost - Pavement Markings

12. Please enter the following cost information of pavement markers being used by your agency

Approx. Unit Acquisition Cost

Approx. Installation cost including labor costs/unit

Approx. Maintenance cost/unit

Approx. life span cost/unit

Additional cost (if any)/unit

Question 13

Snow Plow - Pavement Markings

13. Please answer the following snow plowing procedures related questions.

Please describe the type of snow plowing blades adopted by your agency.

Please describe the snow plowing technique adopted by the agency. For example, use of salt as a part of snow removal operations.

Question 14

14. Do you believe this method of snowplowing damages pavement markers?

Yes

No

If "Yes" please describe why



Question 15

Attributes - Pavement Markings

15. Please provide a satisfaction rating (1 being the lowest and 5 being the highest) for the following recessed pavement marker attributes.

	1.	2.	3.	4.	5.
Visibility of the pavement marker under different weather/light conditions.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Improving travel safety for road-users.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Cost of the pavement markers.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Overall satisfaction with the existing pavement markers being used.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Please indicate type:

Question 16


16. If more than one type of marker being used, continue here:

	1.	2.	3.	4.	5.
Visibility of the pavement marker under different weather/light conditions.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Improving travel safety for road-users.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Cost of the pavement markers.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Overall satisfaction with the existing pavement markers being used.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Please indicate type:

Question 17

17. Additional Comments



The research team thanks you for taking the time to answer the survey.

If you have any questions or comments about this survey, please contact the following individuals.

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