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Cost of Pavement Marking Materials

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David Montebello Jacqueline Schroeder	

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Recent changes in laws regarding the use of volatile organic compounds will impact the type of pavement marking material that many communities use to mark/delineate their roads. This report presents information on the various types of pavement marking materials available. It is intended to provide readers with sufficient data to make educated decisions regarding the selection of an appropriate pavement marking material.

The report pulls together information on pavement marking material terminology, the various types of pavement marking materials, their durability and their retroreflectivity. Changes in formulas relating to laws regulating the use of volatile organic compounds are explained, as well as the impacts of those changes. Additionally, there is a list of best management practices that can be implemented to enable an agency or community to get the most value for its money. The information covered in this report is condensed into an easy to follow table.

The report indicates that for low volume roads (AADT of 10,000 or less) a conventional product (paint) may be the most cost-effective material. For roadways with higher volumes (AADT of 10,000 or more) a more durable product (epoxy or tape) may be more cost-effective and may reduce worker exposure to traffic.

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Cost of Pavement Marking Materials

Final Report

Prepared by

David Montebello, P.E.
and
Jacqueline Schroeder, MP

SRF Consulting Group, Inc.
One Carlson Parkway North, Suite 150
Minneapolis, MN 55447

March 2000

Prepared for the

Minnesota Local Road Research Board
Office of Research Administration
200 Ford Building, Mail Stop 330
117 University Avenue
St Paul, Minnesota 55155

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Mark Maloney, City of Shorview (Chair)

Rick Beck, Minnesota Department of Transportation

Lyle Berg, City of Bloomington

Jim Foldesi, St. Louis County

John Harlow, City of Brooklyn Park

Greg Mills, Traffic Marking Services

Micky Ruiz, Minnesota Department of Transportation

Dan Sauve, Clearwater County

Don Thiesen, Dakota County

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EXECUTIVE SUMMARY

Pavement markings play a key role in the driver's understanding of the roadway and his or her ability to stay on course. By helping the driver stay on course, pavement markings reduce the risk of accidents. Unfortunately, there are limited guidelines that suggest the type of marking material to be used; often material selection is dictated by initial cost. This approach to pavement marking can result in lack of durability, poor retroreflectivity, increased long-term costs and increased staff exposure to traffic. The table on the following pages provides background information on the type of pavement marking materials that are available, including their retroreflectivity, durability, initial application costs, ease of installation, and advantages and disadvantages. It should be noted that:

1. The formula for alkyd paints has been changed to comply with the new environmental rules. The new formula does not contain high levels of volatile organic compounds (VOC); however, it is highly flammable and presents storage problems. The advantage of this material is that it can be used in cold weather, compared to latex, which should not be used below 50^{o} F. It is likely that this product will only be used for cold weather application due to its flammability.

2. For roadways with high AADT (10,000 or more), a more durable product may be a better alternative than paint because it can reduce worker exposure to traffic and maintain a visible line for at least one to four years.

3. Bead application plays an important role in the retroreflectivity of all pavement marking materials. Proper application can lead to increased nighttime visibility and greater line durability.

Measures can be undertaken to ensure that an organization is getting the most for its pavement marking investment. The following list highlights best management practices that can be implemented.

- When hiring a striping contractor, consider providing an option for allowing adjacent communities to be included. In some instances, increasing volumes will lower overall costs.

- If painting is necessary in cooler weather, make sure that contracts allow for the use of Mn/DOT approved low-volume VOC-compliant alkyd paints. Because of Minnesota's cold climate and limited construction season, specifications should be written to allow the use of approved alkyd paint as a substitute for latex paint when pavement temperatures are below 50^{o} F. Communities indicated that lines applied using latex paints on cold pavements are not as durable.

- The cost of applying striping materials is directly related to the quantities, traffic control, material cost and mobilization to and from the job site. The more work that is planned/coordinated to increase quantities and efficiencies, the more cost-effective the project will be.

- If a non-conventional marking material is being considered, the condition of the road must be carefully evaluated to make sure maintenance or other activities will not shorten the life of the pavement marking investment. Also investigate any special mobilization costs for low quantities of specialized materials. When a road is new or has higher traffic volumes, a more durable material could be more cost-effective. Mn/DOT uses durable products on the roadways it maintains in the Twin Cities metropolitan area due to the large volumes of traffic.

- Pre-mix paint is a good choice if conventional paint is the desired marking material. Pre-mix already has half of the reflective beads in the paint. Beads in the paint, as well as beads dropped on the surface, lead to good retroreflectivity of the line as it wears. If all of the beads are on the surface of the painted line (which can occur if beads dropped on top of the paint are not applied properly), the top surface of beads will wear off over time. The line may be visible during the day but not at night.

- Match materials to traffic patterns. Conventional materials (paint) can provide up to three years of life on low-volume roads; however, they provide less than a year's worth of life on high-volume roads (roads with an AADT of 10,000 or more). In high-volume areas or in areas that have significant turning movements, consider durable materials such as epoxies, tapes and preformed thermoplastics. Areas in which large quantities of abrasive materials (sand) are applied during winter months may also warrant the use of durable materials.

- Traffic control is important. While most materials dry relatively quickly, workers and drivers are still exposed to traffic during this time. Proper coning and traffic control help ensure that the marking material stays on the road and workers have a safer environment to perform their work.

- Consider the use of temporary tape for construction zones. This material is more expensive than the conventional materials, but it is easily removed when the construction job is completed.

- Lane marking materials should be applied just off of the crown. This reduces the direct impact that snowplows have on markings.

- If an organization does its own striping, significant consideration should be given to storage and cleanup requirements. Hazardous materials are costly to dispose of and require more specialized training for personnel.

- Before applying any pavement marking material, refer to the Manual on Uniform Traffic Control Devices for appropriate sizing, location and coloring.

- Prepare the road for the marking application. All road surfaces should be clear of debris before the marking material is applied.

- Apply materials according to the manufacturer's directions. Failure to do so may result in poor quality.

MATRIX OF MATERIALS

	Estimated Cost Per Linear Foot[2]	Estimated Life of the Product[3]	Application Temperature	Initial Retroreflectivity[5]	Advantages	Disadvantages
Conventional Products[1]						
Latex	$0.03 - $0.05	9 – 36 months	Air and pavement temperature of 50° F and rising	▪ 275 for white – 180 for yellow with 8 pounds of beads per gallon of paint	▪ Inexpensive ▪ Quick-drying ▪ Longer life on low-volume roads ▪ Easy clean-up and disposal ▪ No collection of hazardous waste products	▪ Short life on high-volume roads ▪ Subject to damage from sands/abrasives ▪ Bead application required ▪ Does not adhere as well to concrete ▪ Pavement must be warm or it will not adhere
Alkyd – New Formula	$0.03 - $0.05	9 – 36 months	Air and pavement temperature of 32° F	▪ 275 for white – 180 for yellow with 8 pounds of beads per gallon of paint	▪ Inexpensive ▪ Quick-drying ▪ Longer-life on low volume roads ▪ Works in cold temperatures	▪ Short life on high-volume roads ▪ Subject to damage from sands/abrasives ▪ Bead application required ▪ Does not adhere as well to concrete ▪ Is highly flammable and requires the use of solvents for clean-up ▪ Has a bad smell
Durable Products						
Mid-durable Paint	$0.08 - $0.10	9 – 36 months[4]	Air and pavement temperature of 50° F and rising	▪ 275 for white – 180 for yellow with 8 pounds of beads per gallon of paint	▪ Inexpensive ▪ Quick-drying ▪ Longer life on low-volume roads ▪ Easy clean-up and disposal ▪ No collection of hazardous waste products	▪ Short life on high-volume roads ▪ Subject to damage from sands/abrasives ▪ Bead application required ▪ Does not adhere as well to concrete ▪ Pavement must be warm or it will not adhere
Epoxy	$0.20 - $0.30	4 years	Air and pavement temperature of 50° F and rising	▪ 300 for white – 200 for yellow with 25 pounds of beads per gallon of epoxy	▪ Longer life on low- and high-volume roads ▪ More retroreflective	▪ Slow-drying ▪ Requires coning and/or flagging during application ▪ Heavy bead application required – may need to be cleaned off of roadway ▪ High initial expense ▪ Subject to damage from sands/abrasives

MATRIX OF MATERIALS (Continued)

	Estimated Cost Per Linear Foot[2]	Estimated Life of the Product[3]	Application Temperature	Initial Retroreflectivity[5]	Advantages	Disadvantages
Tape	$1.50 - $2.65	4 – 8 years	Inlaid in fresh bituminous that is 120° – 150° F Overlaid in an air temperature of at least 60° F and a pavement temperature of 70° F	▪ 350 for white – 250 for yellow	▪ Highly retroreflective ▪ Long life on low- and high-volume roads ▪ Useful in high traffic areas where wheels cross the marking ▪ No beads needed ▪ Reduces worker exposure to road hazards because of long life	▪ High initial expense ▪ Best when used on newly surfaced roads – probably not worth the expense for older roads in poor condition ▪ May suffer snowplow damage
Preformed Thermoplastic	NA	3 – 6 years	All temperatures	▪ 275 for white – 180 for yellow	▪ Long life on low- and high-volume roads ▪ Retroreflective ▪ No beads needed ▪ Any temperature for application	▪ Only used for symbols – not used for edge lines, centerlines or skip lines ▪ Subject to damage from sands/abrasives ▪ May suffer snowplow damage
Temporary Products						
Temporary Tape	$1.10 - $1.50	Length of construction	Air and pavement temperature of 35° F and rising	▪ At least 275 for white – 180 for yellow	▪ Does not damage new pavement ▪ Lasts the life of the construction ▪ Easily applied and removed	▪ Only for use in construction zones

(1) Conventional products are available in a pre-mix form. The pre-mix has half of the beads already in the paint. This makes the application easier and enables more of the dropped on beads to adhere to the paint. The pre-mix gives the user higher retroreflectivity for a longer period of time.

(2) Price estimates are for a minimum of 20,000 linear feet; lower quantities will result in higher prices. Prices are in 1999 dollars.

(3) Life of the pavement marking material will depend upon road volumes, the amount of sand used in winter, application and road condition.

(4) Life of mid-durable paint has not been thoroughly field tested because it is a new product. The manufacturers of the product claim that it has an enhanced life over other latex paints. In areas where latex may last only a season, the user might get two seasons. In areas where latex lasts longer than a single season the user may get additional seasons out of the mid-durable.

(5) All numbers are measured in $mcd/m^2/lux$.

CHAPTER 1
INTRODUCTION

County and city engineers and other public officials understand the need to mark roadways. Pavement markings play a key role in the driver's understanding of the roadway and his or her ability to stay on course. By helping the driver stay on course, pavement markings reduce the risk of accidents.

There are many manufactures of pavement marking materials competing for communities' business. The manufacturers distribute information on their products and on the competition's products, making comparisons difficult to understand and somewhat unreliable. For those trying to decide what material to use, conflicting information can make it difficult to reach a rational decision. What are the characteristics, costs, and benefits of the different pavement marking materials? What factors should one consider when selecting the type of pavement marking material for a particular road?

This report presents information on the various types of pavement marking materials available including the most common types of materials, their retroreflectivity, their durability, their initial application costs, their ease of installation and the relative cost savings to the public and the community as a result of marking.

Since there are limited guidelines that suggest the type of pavement marking material to be used, often the decision of what material to use is dictated by the initial cost. This approach to pavement marking can result in lack of durability, poor retroreflectivity, increased long-term costs and increased exposure to traffic for staff. It is the intent of this report to provide background information to assist county, city and township engineers and officials with the

selection of appropriate pavement marking materials. It should be noted that the recommendations provided in this report are to be used only as a tool; they are not intended to serve as official policy.

The information provided in this report is divided in to four sections and an appendix:

Section 1: Pavement Marking Terminology

Provides the reader with the terminology that will be used to describe the elements and properties of the various pavement marking materials referenced throughout this report.

Section 2: Pavement Marking Materials

Pavement marking materials, their uses, costs, reflectivity and durability are explained. Included in this section are reference sheets by material type and a matrix highlighting the advantages and disadvantages of the different pavement marking materials.

Section 3: Benefits of Pavement Marking

Depicts the benefits (in terms of dollars) of striping roadways.

Section 4: Best Management Practices

Underscores the importance of initiating some best management practices.

Appendix: Life Cycle Cost Estimates

The appendix provides the user with an example for calculating life cycle cost numbers for pavement marking materials.

CHAPTER 2
PAVEMENT MARKING TERMINOLOGY

The reader's ability to understand the various pavement marking materials and their associated benefits and drawbacks is dependent upon a basic understanding of pavement marking terminology. Because of the large number of manufacturers many terms are used to describe a single type of marking material. With the aim of clarifying the terminology, this section provides the definitions of the most prevalent expressions.

Alkyd Paints

Alkyds are conventional paints that are solvent-based. They are quick drying paints that no longer contain hazardous amounts of volatile organic carbons. They do, however, contain a highly flammable base material and require the use of harsh solvents to remove the paint from equipment.

Centerline

The yellow line separating opposing traffic.

Conventional Products

Conventional products include latex and alkyd paints. These products have a shorter life span than durable products.

Durable Products

Durable products include epoxy, thermoplastics and poly preformed tapes. These products generally have a longer life span than conventional products.

Durability

Durability refers to a product's ability to withstand damage. The life cycle of a product is taken into consideration when evaluating durability.

Edge Line

White or yellow solid lines.

1. White solid lines delineate the right-most driving lane from the shoulder or ditch of the road.
2. Yellow solid lines delineate the left-most lane of traffic from the shoulder or ditch of the roadway, or the left edge of a one-way roadway.

Epoxy

Often referred to as "epoxy paint." Epoxy is a durable pavement marking material that is made up of two components. One component is the pigment and the second component is the hardener. Each component is heated separately and then thoroughly mixed and applied at a temperature of $43^{o} \pm 1^{o}$ C ($110^{o} \pm 30^{o}$ F). Epoxy comes in two forms: fast-dry and slow-dry.

Glass Beads

Glass beads are tiny spherical glass balls that are used to make pavement marking materials retroreflective. Glass beads are dropped on top of freshly applied conventional paints and durable materials such as epoxies. In some cases, portions of the beads are mixed in with paint before it is applied (pre-mixed paint). Glass beads can also be untreated or treated. Treated glass beads have a coating on their surface that enables the bead to sink into the paint, while the untreated beads float on the surface. Having a portion of the beads on the surface and in the paint allow continued retroreflectivity as the paint wears. The same result can be achieved by using the pre-mixed paints and dropping on untreated beads. The proper application of beads is key in creating the marking's retroreflectivity.

Heavy Metals

Toxic materials defined by the United States Environmental Protection Agency that are not allowed to be included in pavement marking materials because of their threat to the environment and to the users of the product. Toxic heavy metals include lead, cadmium, mercury and hexavalent chromium.

High-Volume Roadway

Roadways with an AADT of 10,000 or greater.

Lane Line

The lane line is the white broken (skip) line that delineates lanes of concurrent-flow traffic on multi-lane roads.

Latex Paints

A pavement marking that is water-based. It is typically considered a conventional material; however, it does come in a mid-durable formula. Latex is a quick dry material.

Lead

Lead is a toxic heavy metal that was a component of conventional paints. The use of lead is no longer allowed under most circumstances.

Oil-Based Paints

Oil-based paints are the same as alkyd paints (solvent-based).

Paint

Paint is a conventional pavement marking material. It can be solvent-based or water-based. Often epoxy is referred to as "epoxy paint," even though it is not a paint or a conventional pavement marking material.

Pavement Markings

Edge lines, centerlines, lane lines and symbols that are placed on pavement or curb surfaces. They are used to provide direction to drivers.

Pre-mix

Conventional paint with glass beads in it. Pre-mix is available in latex and alkyd paints.

Plastic Preformed Pavement Marking Material

Often referred to as "tape," this material is durable. The material is made up of plastic that is heated into the pavement surface. Plastic preforms can be used for symbols, legends and crosswalks.

Poly Preformed Pavement Marking Material

Often referred to as "tape," this material is durable. The material is typically inlaid into freshly placed bituminous surfaces. It can, however, be glued into place on older bituminous or concrete surfaces.

Quick-Dry Paints

Paints that dry in three minutes or less are called quick-dry. They may also be referred to as fast–dry.

Retroreflectivity

Retroreflectivity refers to reflection in which originating light is turned in directions close to the direction from which it came. The retroreflectivity of the pavement marking material makes it visible to drivers at night when their vehicle's headlights reflect off the material. It is usually measured in candelas/lux/square meter, which is equivalent to candelas/foot-candle/square foot. Even though the Manual on Uniform Traffic Control Devices does not specify a minimum

retroreflective level for pavement marking materials, the Minnesota Department of Transportation views the minimum acceptable initial retroreflectivity level to be 180 mcd/m^2/lux for yellow material and 275 mcd/m^2/lux for white material (Mn/DOT specs for alkyd and latex paints).

Slow-Dry Materials

Products that take longer than three minutes to dry are called slow-dry. They are usually the epoxies or thermoplastics. Traffic control such as coning and/or flagging is required when applying these materials.

Solvent-borne Paints

Solvent-borne paints are alkyd paints. The new formula no longer contains hazardous amounts of volatile organic compounds.

Tapes

Tapes are also referred to as "preforms." This is a durable marking product that is inlaid on freshly laid bituminous surfaces or is tamped onto concrete and older bituminous surfaces.

Temporary Tape

Temporary tape is a pavement marking material that is used at many construction sites or work zones for a short period of time. It is often used to delineate lane shifts and changes on newly completed road surfaces. Temporary tape is used in these instances so that the newly completed surface is not damaged by abrasive cleaning techniques needed to remove the more permanent marking materials. The material comes on a roll and is laid on top of the road surface and tamped down. When construction is complete, the material can be lifted off the road surface.

Thermoplastics

Thermoplastics are a durable pavement marking material composed of glass beads, pigments, binders (plastics and resins) and fillers. There are two types of thermoplastics: hydrocarbon and alkyd. Hydrocarbon thermoplastics are made from petroleum-derived resins; and alkyd thermoplastics are made from wood-derived resins. Thermoplastics are originally in a granular or block form. They are then heated to a temperature of at least 400^{o} F and sprayed onto the pavement.

Thermosets

Epoxy and polyester are thermosets. Thermosets are durable pavement marking materials that are sprayed onto the road surface with glass beads dropped on top.

Volatile Organic Compounds

Volatile organic compound means any organic compound that participates in atmospheric photochemical reactions. These reactions are not good for the environment and as a result, many of the products that have high levels of these compounds have been prohibited.

Water Borne Paints

Water-borne paints are latex paints.

CHAPTER 3
PAVEMENT MARKING MATERIALS

Pavement marking materials have changed dramatically over the past several years. New products are on the market that were not used consistently as little as five years ago. Old products that were highly dependable are no longer available for use because they contained lead, other heavy metals or high levels of volatile organic compounds. This section provides the reader with information on the types of products available at this time, to assist in determining what type of material is appropriate for the reader's community. New materials are constantly introduced to the market, as a result, agencies should continue to monitor what is new and available for use.

There are two important components to evaluate when deciding which pavement marking material to use. The first component is the line or the marking that is put on the pavement; it is visible during the day. The second component, the retroreflectivity, is the part visible at night when headlights reflect off of the line. Both components are necessary for the marking to be useful to drivers. Typically, beads are dropped on top of the material that is used to make the line to give the marking its retroreflectivity.

As stated above, there are many different pavement marking materials on the market. In order to understand the products that are available and to explain their advantages and disadvantages, the materials are placed into a matrix that highlights their various properties. A more in depth look at the products is provided following the matrix. The products are divided into three categories – conventional materials, durable materials and temporary pavement marking materials.

All costs and life expectancy numbers included in the matrix are estimates. There are variations in cost depending upon the manufacturer and the quantities ordered. Generally, the more material ordered, the lower the price. The expected life of a material can vary depending on the manufacturer, the installer, the cleanliness of the pavement, the application of the beads and the condition of the pavement that the material is being placed upon. Regardless of what type of pavement marking material is chosen, the condition of the roadway or surface pavement should

be taken into consideration. Roads that are in poor repair will have difficulty retaining the marking material.

Conventional Pavement Marking Materials

Conventional pavement marking materials, as previously described, are latex and alkyd paints. These products are typically inexpensive and may have a relatively short life span. The following sections describe a material type, including its retroreflectivity, durability, ease of application and cost per linear foot.

Latex

Latex paints are water-based. Latex is becoming increasingly popular as a pavement marking material because of its low cost and ease in cleaning up and disposing of left over paint. Latex paints typically cost between $0.03 and $0.05 per linear foot installed. Latex is also more environmentally friendly than most pavement marking materials; it does not contain lead, other heavy metals or volatile organic compounds that are hazardous to the environment and to those applying it. Because latex is more environmentally friendly than the new alkyd paints (discussed in the next section) and is comparable in cost, it is likely that latex will be promoted for use by striping companies.

When applied, latex paints should have initial retroreflectivity readings of at least 275 mcd/m^2/lux for white and at least 180 mcd/m^2/lux for yellow.

TABLE 3.1 MATRIX OF MATERIALS

	Estimated Cost Per Linear Foot[2]	Estimated Life of the Product[3]	Application Temperature	Initial Retroreflectivity[5]	Advantages	Disadvantages
Conventional Products[1]						
Latex	$0.03 - $0.05	9 – 36 months	Air and pavement temperature of 50° F and rising	▪ 275 for white – 180 for yellow with 8 pounds of beads per gallon of paint	▪ Inexpensive ▪ Quick-drying ▪ Longer life on low-volume roads ▪ Easy clean-up and disposal ▪ No collection of hazardous waste products	▪ Short life on high-volume roads ▪ Subject to damage from sands/abrasives ▪ Bead application required ▪ Does not adhere as well to concrete ▪ Pavement must be warm or it will not adhere
Alkyd – New Formula	$0.03 - $0.05	9 – 36 months	Air and pavement temperature of 32° F	▪ 275 for white – 180 for yellow with 8 pounds of beads per gallon of paint	▪ Inexpensive ▪ Quick-drying ▪ Longer-life on low volume roads ▪ Works in cold temperatures	▪ Short life on high-volume roads ▪ Subject to damage from sands/abrasives ▪ Bead application required ▪ Does not adhere as well to concrete ▪ Is highly flammable and requires the use of solvents for clean-up ▪ Has a bad smell
Durable Products						
Mid-durable Paint	$0.08 - $0.10	9 – 36 months[4]	Air and pavement temperature of 50° F and rising	▪ 275 for white – 180 for yellow with 8 pounds of beads per gallon of paint	▪ Inexpensive ▪ Quick-drying ▪ Longer life on low-volume roads ▪ Easy clean-up and disposal ▪ No collection of hazardous waste products	▪ Short life on high-volume roads ▪ Subject to damage from sands/abrasives ▪ Bead application required ▪ Does not adhere as well to concrete ▪ Pavement must be warm or it will not adhere
Epoxy	$0.20 - $0.30	4 years	Air and pavement temperature of 50° F and rising	▪ 300 for white – 200 for yellow with 25 pounds of beads per gallon of epoxy	▪ Longer life on low- and high-volume roads ▪ More retroreflective	▪ Slow-drying ▪ Requires coning and/or flagging during application ▪ Heavy bead application required – may need to be cleaned off of roadway ▪ High initial expense ▪ Subject to damage from

						sands/abrasives

TABLE 3.1 MATRIX OF MATERIALS (Continued)

	Estimated Cost Per Linear Foot[2]	Estimated Life of the Product[3]	Application Temperature	Initial Retroreflectivity[5]	Advantages	Disadvantages
Tape	$1.50 - $2.65	4 – 8 years	Inlaid in fresh bituminous that is 120° – 150° F Overlaid in an air temperature of at least 60° F and a pavement temperature of 70° F	▪ 350 for white – 250 for yellow	▪ Highly retroreflective ▪ Long life on low- and high-volume roads ▪ Useful in high traffic areas where wheels cross the marking ▪ No beads needed ▪ Reduces worker exposure to road hazards because of long life	▪ High initial expense ▪ Best when used on newly surfaced roads – probably not worth the expense for older roads in poor condition ▪ May suffer snowplow damage
Preformed Thermoplastic	NA	3 – 6 years	All temperatures	▪ 275 for white – 180 for yellow	▪ Long life on low- and high-volume roads ▪ Retroreflective ▪ No beads needed ▪ Any temperature for application	▪ Only used for symbols – not used for edge lines, centerlines or skip lines ▪ Subject to damage from sands/abrasives ▪ May suffer snowplow damage
Temporary Products						
Temporary Tape	$1.10 - $1.50	Length of construction	Air and pavement temperature of 35° F and rising	▪ At least 275 for white – 180 for yellow	▪ Does not damage new pavement ▪ Lasts the life of the construction ▪ Easily applied and removed	▪ Only for use in construction zones

(1) Conventional products are available in a pre-mix form. The pre-mix has half of the beads already in the paint. This makes the application easier and enables more of the dropped on beads to adhere to the paint. The pre-mix gives the user higher retroreflectivity for a longer period of time.

(2) Price estimates are for a minimum of 20,000 linear feet; lower quantities will result in higher prices. Prices are in 1999 dollars.

(3) Life of the pavement marking material will depend upon road volumes, the amount of sand used in winter, application and road condition.

(4) Life of mid-durable paint has not been thoroughly field tested because it is a new product. The manufacturers of the product claim that it has an enhanced life over other latex paints. In areas where latex may last only a season, the user might get two seasons. In areas where latex lasts longer than a single season the user may get additional seasons out of the mid-durable.

(5) All numbers are measured in $mcd/m^2/lux$.

A drawback of using latex paint, or any paint for that matter, is that it is not as long lasting as a durable material. Studies by the Minnesota Department of Transportation indicate a short life span for latex in high-volume areas (areas with an AADT of 10,000 or more). The paint generally is good for no more than a year in high volume areas, and probably should be replaced after nine months. Areas that have lower traffic volumes will get longer life from the latex and alkyd paints. In some areas, markings may last as long as three years. Some counties have had good success in applying latex paint over epoxy lines that are visible by day but have lost reflectivity at night.

Latex and alkyd paints (discussed in the next section) are two of the easier pavement marking materials to apply. They both can be used on concrete or bituminous pavement, and they dry quickly. It should be noted that both latex and alkyd materials adhere better to bituminous pavement than they do concrete pavement. The latex or alkyd is applied using a machine that is capable of applying the material under pressure at a controlled temperature through a spray nozzle. The vehicle spraying the paint should also be capable of applying glass beads at a rate of eight pounds per gallon immediately after applying the paint.

The application of beads is critical to a marking's retroreflectivity whether latex, alkyd or epoxy is used. Failure to properly set the beads in the material results in poor nighttime performance. Beads that are forced too far into the marking material will not reflect light back to the driver when a vehicle's headlights shine on the marking; and beads that are not deep enough into the marking material are easily removed. This also results in poor reflectivity. In order to help reduce some of the errors that can occur with bead application some communities and agencies use a pre-mixed paint formula (discussed below). Other communities and agencies buy beads that are treated with a material and mix them with untreated beads. This mixture enables some of the beads to sink into the paint and others to rise to the surface, thereby getting the balance needed to ensure proper retroreflectivity.

When applying latex, the pavement temperature should be at least 50^{o} F or the paint will not adhere to the pavement.

Alkyd

Alkyd paint has undergone a transformation. New rules by the Environmental Protection Agency have changed the formula used to make the alkyd paint that is sold in quantities over five gallons (the old formula is still being sold, but only in containers that are five gallons or less). Alkyds are still solvent-based paints; however, they no longer contain high levels of volatile organic compounds. Information on the paint with the latest formula is limited because of its newness.

The new alkyd is still low in cost and has a quick drying time. It can be used on both concrete and bituminous surfaces, although it adheres better to the bituminous surfaces. The new alkyd is similar to latex in that it typically costs between $0.03 and $0.05 per linear foot to apply.

Alkyd is not as retroreflective as some of the durable pavement marking materials; however, it has similar retroreflectivity to latex. When applied, alkyd paints should have initial readings of at least 250 mcd/m^2/lux for white and at least 150 mcd/m^2/lux for yellow.

The old alkyds, like latex, were not very durable in high volume areas. Durability information on the new formula is not yet available; however, paint experts suggest that the expected life of the new material should be comparable to the old material. Studies of the old formula conducted by the Minnesota Department of Transportation indicate a life expectancy similar to that of a latex paint. The alkyd paint is generally good for no more than a year, and probably should be replaced after nine months in high-volume areas. Areas that have lower traffic volumes will get more use from the alkyd paints. In these areas markings may last as long as three years.

The application process for alkyds is the same as it is for latex with one major exception (see the latex discussion above for a description of the application process). Alkyds can be used at colder temperatures than the latex paints. The pavement temperature must be at least 50^{o} for latex application or the material will not adhere to the pavement. Application for alkyds simply requires the air temperature to be above freezing so that the spray nozzle and air lines do not freeze.

Like their latex counterpart, the new alkyds are volatile organic compound compliant. Alkyds contain no heavy metals and contain only low amounts of the volatile organic compounds (VOCs) that are harmful to the environment. Unfortunately, the new formula utilizes acetone, a highly flammable chemical. This makes storage of the material difficult and dangerous. In addition to the flammable nature of the new formula, it also has a smell that may be offensive to those who apply the material. Additionally, cleaning equipment that has been used to apply alkyd paints requires the use of solvents that pose some environmental concerns. Because of these risks, it is likely that the use of the new alkyd paints will be limited to cold weather applications.

Pre-Mix Formulas for Latex and Alkyd Paints

Pre-mix paints are an alternative to the regular conventional pavement markings. The advantage of using the pre-mix paint is that half of the required glass beads, which give the marking its retroreflectivity, are already in the latex or alkyd paint. The applicator only has to worry about dropping four pounds of glass beads per gallon on top of the paint. The pre-mix makes the application cleaner (less beads to scatter) and more accurate (beads are on the pavement marking line – not the roadway). It also helps ensure that some of the beads will be sunk into the marking material and that some of the beads (the ones dropped after the application of the paint) will be on the surface. This decreases the likelihood of bead application error and helps ensure good retroreflectivity. Retroreflectivity levels for newly applied pre-mixed paint should meet or exceed the suggested minimum of 250 mcd/m^2/lux for white and 150 mcd/m^2/lux for yellow.

Pre-mix paints come in both latex and alkyd formulas and are quick-drying. The applicator simply needs to ensure that the air and pavement surface temperatures are 50^{o} F and rising when

using latex. The price of the pre-mix paint is the same as the cost of latex and alkyd paints - $0.03 to $0.05 per linear foot.

Durable Pavement Marking Materials

Durable pavement marking materials, as their name suggests, have a longer life expectancy than conventional pavement marking materials. While these materials will not last forever, they should give the road authority a longer life than the conventional products. These products typically are more expensive than their conventional counterparts and are generally more difficult to apply to the pavement surface. The following sections describe a material type, including its retroreflectivity, durability, ease of application and cost per linear foot.

Mid-Durable Paint

Mid-durable paints are relatively new products that are said to have a longer life span than the typical latex or alkyd paint. Because they have not been used for a long period of time, there is little reliable information on the mid-durables' life expectancy. The manufacturers of the product claim that the user of the mid-durable is going to get additional wear out of the product than with a typical latex. The manufacturers state that under certain traffic conditions, this additional life is likely to result in an extra season; under other conditions, it may gain a year or two of life over the latex and alkyd paints.

The mid-durable paints are high-quality water-based paints that are applied at double the level of typical latex. The ability to apply a thicker coat of paint enables the paint to last longer. When initially applied, the mid-durable meets the suggested minimum retroreflectivity of 250 mcd/m^2/lux for white and an initial reading of at least 150 mcd/m^2/lux for yellow.

The cost of the mid-durable paint is approximately 30 percent more than the typical latex, however, because it is applied at a level that is twice as thick as the typical latex, twice as much paint is needed. As a result, the mid-durables typically cost $0.08 to $0.10 per linear foot.

Thermosets – Epoxy and Polyester

Thermosets are becoming increasingly popular as their durability becomes known. Thermosets are a durable pavement marking material that typically is in the form of an epoxy or polyester. Epoxy is the more common material, and as a result is the one that will be discussed in greater detail in this section.

Epoxy is often referred to as "epoxy paint" because of its superficial resemblance to paint. Epoxy is a durable pavement marking material that is made up of two components. One component is the pigment and the second component is a hardener.

Application of epoxy requires specialized equipment and well-trained operators. As with the conventional materials, the air and pavement temperature should be at least 50^{o} F, and the pavement surface should be cleaned prior to the application. Each component of the epoxy is heated separately and then thoroughly mixed and applied at a temperature of $43^{o} \pm 1^{o}$ C ($110^{o} \pm 30^{o}$ F). Following the application of the epoxy, glass beads are added to give the marking its retroreflectivity. One of the drawbacks to using epoxy is the large number of glass beads that are dropped on top of it. Epoxy generally requires three times the number of beads as do the conventional materials. In part, such a large number of beads are needed to prevent cars from tracking the epoxy before it sets.

Epoxy comes in two forms, fast-dry and slow-dry. The fast-dry (also known as Type I) is a fast-curing material suitable for line applications. Under ideal conditions, application of this product may not require coning. The slow-dry (also known as Type II) is a slow-curing material suitable for all applications of pavement markings. This material always requires controlled traffic conditions (i.e., coning and/or flagging).

Epoxy is initially more retroreflective than the conventional pavement marking materials. Studies conducted by the Minnesota Department of Transportation indicate the initial retroreflectivity is around 300 mcd/m^2/lux for white and around 220 mcd/m^2/lux for yellow. The number of beads that are dropped on top of the marking as the material is applied may skew the initial retroreflectivity. As mentioned above, three times the number of beads are applied to epoxy as there are to the paints. Some organizations have found that the retroreflectivity of the epoxy does not last as long as the marking on the pavement. One way to address the long-term

retroreflectivity issues associated with epoxy is to go over the epoxy with latex paint. The fresh coat of latex will provide retroreflectivity to the marking.

Epoxy is more expensive than the conventional paints described in the previous section. However, it also lasts longer. Epoxies generally cost between $0.24 and $0.30 per linear foot as compared to $0.05 per linear foot for the conventional paints. The increased initial cost may be worth the investment in epoxy on high volume roadways due to the cost savings in labor and potential injuries to workers. Additionally, administrative time and expenses are reduced if contracts do not have to be let on an annual basis.

Epoxy is made up of epoxy resins and pigments that are required to be free of lead and other toxic heavy metals. In addition, no solvents are to be given off to the environment when the material is applied to the pavement surface. Cleaning equipment used to apply the epoxy may require the use of solvents that negatively impact the environment.

A Minnesota company has developed a new thermoset that is not an epoxy or polyester. It is a polyurea that is designed to give a longer life than epoxies. The new material is supposed to offer some advantages over epoxy in that it sets within 180 seconds, does not require any beads to be dropped on top of it, it lasts longer, has little waste and limited clean-up, and will harden when the pavement is wet. Anticipated life on this product is approximately six to eight years. This material is being tested in some communities. Currently the material costs $0.50 a linear foot. This product should be coming to the market place within a year.

Thermoplastics

Thermoplastics are durable pavement marking materials that have been successfully used in warmer climates for a number of years. They are made up of glass beads, binders, pigments and filler materials. The glass beads, along with the pigment, give the material its retroreflectivity. The binder, which is a mixture of plasticizer and resins, holds the other components together. Pigments provide color and retroreflectivity, and the fillers contain inert substances that provide bulk.

There are two types of thermoplastic available, named according to the binder used. Hydrocarbon thermoplastic is made up of petroleum derived resins. This material is heat stable and, as a result, has a more predictable and easier application process. Because the material is made up of petroleum-derived resins, it is sensitive to oil drippings and other automobile byproducts. It is therefore recommended for centerlines, edge lines and skip lines rather than for high-traffic areas where cars are stationary (i.e., stop bars, crosswalks, turn arrows and railroad crossings). The second material type is alkyd thermoplastic. This material is made from wood-derived resins that are resistant to petroleum products. The alkyd material is generally more durable and has higher retroreflectivity values. It is recommend for inner city markings and high-traffic areas where petroleum drippings are common.

Application of thermoplastics is not easy; it requires a great deal of skill and diligence, as well as special equipment. The first step in the application process is to prime the road surface if it is concrete or asphalt older than two years. The next step is to heat the material to a temperature between 400^{o} and 440^{o} F. If the material is being applied to cement surfaces, the material should be heated to a temperature of at least 425^{o} F. The pavement and air temperature should be at least 50^{o} F; if not, the material will not adhere to the road surface. Once sprayed onto the pavement, glass beads need to be applied at a rate of eight to 10 pounds per 100 ft^2.

Thermoplastics, when initially applied, should exceed the minimum 275 mcd/m^2/lux for materials and an initial reading of at least 180 mcd/m^2/lux for yellow. In general, these materials are more retroreflective than the conventional marking materials. Variations in retroreflectivity can occur, depending upon the manufacturer, the pavement surface and the applicator.

The life of a thermoplastic is significantly longer than the life of conventional pavement marking materials. In the proper climate, thermoplastics can last three to six years. Unfortunately, snowplows damage the thermoplastics. As a result, their use as pavement markings in Minnesota is limited. Thermoplastics are not recommended for use in Minnesota for centerlines, skip lines or edge lines due to the state's climate and maintenance requirements.

Poly Preform/Tape

Poly preformed marking materials are commonly referred to as "tape." These materials should not be confused with preformed thermoplastics and temporary tape. Preformed thermoplastics will be described below, and temporary tape will be discussed in the temporary products section of this chapter.

Tape is a durable pavement marking material that is either inlaid into freshly placed bituminous or overlaid onto old bituminous or Portland Concrete. Tape seems to work best when it is inlaid into the bituminous. When inlaid, the material is resistant to snowplow damage.

The process of inlay or overlay, as mentioned above, can be used to install tape. The inlay method involves rolling the material into freshly compacted asphalt. After the asphalt pavement compaction is complete, the surface to which the tape is to be applied should be marked. Once marked, the tape is applied and rolled into the surface with the use of a finishing roller. For symbols and legends, a manual roller may be needed.

The overlay method is used on Portland Concrete and older bituminous surfaces. When this method is used, it is important that the pavement surface be properly prepared with primer that will help the product adhere to the road. Once primed, the pavement marking material is placed upon the road surface and tamped down. Since the tape is slightly higher than the road surface, this method of installation is more susceptible to plow damage.

Compared to many of the other products, tape is highly retroreflective and durable. Initial readings of the tape are at least 350 mcd/m^2/lux for white and 250 mcd/m^2/lux for yellow. Additionally, tape is expected to last four to eight years – longer than most of the other materials.

Unfortunately, higher costs go along with the higher durability. Tape costs approximately $1.50 to $2.65 per linear foot. The increased initial cost may be worth the investment in tape due to the cost savings in labor and potential injuries to workers. Additionally, administrative time and expenses are reduced if contracts do not have to be let on an annual basis.

Preformed Thermoplastics

Preformed thermoplastics are durable pavement marking materials that are primarily used on high-volume roadways for symbols, legends and crosswalks. Unlike the thermoplastics that are sprayed onto the pavement surface for edge lines and centerlines, preformed thermoplastics melted into the roadway for symbols, legends and crosswalks are not as likely to be subject to snowplow damage if properly applied.

Preformed thermoplastics are applied to clean and dry pavement surfaces. The thermoplastic is placed on top of the road surface and heated until it melts into the roadway. If the material is being used on Portland Cement, a sealer needs to be applied. The preformed thermoplastics work better on bituminous surfaces.

The material exceeds the recommended minimum of 250 mcd/m^2/lux for white and 180 mcd/m^2/lux for yellow. Thermoplastics are durable and should remain retroreflective for three to six years.

The increased initial cost may be worth the investment in preformed thermoplastics for symbols in high volume areas due to the cost savings in labor and potential injuries to workers. Additionally, administrative time and expenses are reduced if contracts do not have to be let on an annual basis.

Temporary Products

Temporary Tape

Temporary tape is a material that is frequently used in construction zones. This material has advantages over traditional means of pavement marking materials for construction zones because removal does not require chemical treatments or sandblasting. Because the product is used for a limited time, it is not durable.

CHAPTER 4
BENEFITS OF PAVEMENT MARKING

For many drivers, centerlines and edge lines provide security and a sense of safety when traveling. Psychologically and physically, they give the driver a barrier that provides protection from oncoming vehicles and vehicles in adjacent lanes. Engineers and public officials know that pavement markings save lives and reduce congestion and conflicts. Unfortunately, in some areas, marking does not occur or is inconsistent due to cost constraints. This provides information on the benefits of maintaining consistent pavement marking along roadways.

A 1992 benefit-cost analysis conducted by Ted Miller determined that longitudinal pavement markings (edge lines, centerlines and lane lines) were cost-effective on all roadway types. Miller concluded that nationally, pavement striping has a benefit-cost ratio of 60. This means that for each dollar spent on longitudinal pavement marking, there is a $60 return in terms of increased safety and congestion benefits. On average, this is a $19,226 benefit over one mile. Miller also concluded that in climates where thermoplastic markings are practical, their long life makes their life cycle costs competitive with painted markings.

Miller found the lowest benefit-cost ratios for longitudinal pavement markings are for edge lines on rural two-lane highways. Even so, they still produce a $17 return for every dollar spent if there are 500 ADT. As a result, these markings are justified if an average on one non-intersection crash occurs annually every 15.5 miles.

Although prices for pavement marking materials have increased since Miller completed his study, the costs associated with crashes have also increased. The work he did in 1992 is still applicable today.

The following paragraphs explain Miller's formulas.

Miller calculated his annualized application costs by utilizing the following formula:*

$$C = M+P+E+Admin$$

where,

M = annualized materials costs
P = annualized personnel costs
E = annualized cost of equipment and storage facilities
Admin = annualized contract letting, monitoring and other administrative costs

* The annualized costs included multiple applications for those materials whose useful life is less than a year.

* The formula that Miller used included a discount rate of 4 percent (a rate recommended for use in analyzing highway safety measures with lives less than five years).

* Miller priced high-solvent paint at $0.35 per linear foot in rural areas and at $0.07 per linear foot in urban areas. He priced thermoplastics at an average of $0.32 per linear foot. The costs for the paint assume that painting will involve retracing existing lines. Striping after repaving or chip sealing requires premarking to establish line locations. This costs approximately an additional $0.005 to $0.01 per linear foot.

* The cost of contract letting and monitoring is approximately 5 to 7 percent of the contract price.

By using his formula, Miller determined that annual costs for applying paint materials is:

$381 per mile for rural interstate striping
$192 per mile for other rural roads
$762 per mile for urban freeways and major urban arterials
$385 per mile for other urban roads

and for using thermoplastic marking materials the costs are approximately:

$308 per mile for rural roads
$391 per mile for urban roads

Miller calculated the annual benefits to the travelling public of pavement marking by using the following formula*:

$$B = A*R*CS+V*T(1/S_0 - 1/S)$$

where,

A = crashes per year on road segment
R = fractional reduction in crashes expected due to marking
CS = cost savings per crash prevented
V = annual traffic volume on road segments
T = value of vehicle hour of travel time
S_0 = average speed on road segment before marking
S = average speed on road segment after marking

* The average benefit per crash prevented is $95,000. This figure represents the entire range of crash type from fatality to property damage.

* Adding edge lines to a centerline yields an 8 percent reduction in crashes.

* Vehicle hour of travel time was calculated at $8.84 per hour. It was evaluated only on interstates, freeways and arterials.

CHAPTER 5
BEST MANAGEMENT PRACTICES

There are measures that can be undertaken by an organization to ensure that it is getting the most for its money in terms of pavement marking. This section of the report highlights some of those measures that can be used to ensure a cost-effective pavement marking budget.

1. When hiring a contractor, consider providing an option for allowing adjacent communities to be included. In some instances, increasing volumes will lower overall costs.

2. If painting is necessary in cooler weather, make sure that contracts allow for the use of Mn/DOT approved low-volume VOC-compliant alkyd paints. Because of Minnesota's cold climate and limited construction season, specifications should be written to allow the use of approved alkyd paint as a substitute for latex paint when pavement temperatures are below 50^{o} F. Communities indicated that lines applied using latex paints on cold pavements are not as durable.

3. The cost of applying striping materials is directly related to the quantities, traffic control, material cost and mobilization to and from the job site. The more work that is planned/coordinated to increase quantities and efficiencies, the more cost-effective the project will be.

4. If a non-conventional marking material is being considered, the condition of the road must be carefully evaluated to make sure maintenance or other activities will not shorten the life of the pavement marking investment. Also investigate any special mobilization costs for low quantities of specialized materials. When a road is new or has higher traffic volumes, a more durable material could be more cost-effective. Mn/DOT uses durable products on the roadways it maintains in the Twin Cities metropolitan area due to the large volumes of traffic.

Pre-mix paint is a good choice if conventional paint is the desired marking material. Pre-mix already has half of the reflective beads in the paint. Beads in the paint, as well as beads dropped on the surface, lead to good retroreflectivity of the line as it wears. If all of the beads are on the surface of the painted line (which can occur if beads dropped on top of the paint are not applied properly) the top surface of the beads will wear off over time. The line may be visible during the day but not at night.

5. Match materials to traffic patterns. Conventional materials (paint) can provide up to three years of life on low-volume roads; however, they provide less than a year's worth of life on high-volume roads (roads with an AADT of 10,000 or more). In high-volume areas or in areas that have significant turning movements, consider durable materials such as epoxies, tapes and preformed thermoplastics. Areas in which large quantities of abrasive materials (sand) are applied during winter months may also warrant the use of durable materials.

6. Traffic control is important. While most materials dry relatively quickly, workers and drivers are still exposed to traffic during this time. Proper coning and traffic control help ensure that the marking material stays on the road and workers have a safer environment to perform their work.

7. Consider the use of temporary tape for construction zones. This material is more expensive than the conventional materials, but it is easily removed when the construction job is completed.

8. Lane marking materials should be applied just off the crown. This reduces the direct impact that snowplows have on markings.

9. If an organization does its own striping, significant consideration should be given to storage and cleanup requirements. Hazardous materials are costly to dispose of and require more specialized training for personnel.

10. Before applying any pavement marking material, refer to the Manual on Uniform Traffic Control Devices for appropriate sizing, location and coloring.

11. Prepare the roads for the marking application. All road surfaces should be clear of debris before the marking material is applied.

12. Apply materials according to the manufacturer's directions. Failure to do so may result in poor quality.

CHAPTER 6
WORKS CONSULTED

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APPENDIX
LIFE CYCLE CALCULATIONS

The committee that developed this research report wanted to provide the reader with life cycle cost calculations. Unfortunately, there are a number of variables that can impact the life of a given marking material. Therefore, it is impossible for this report to calculate life cycle costs for each possibility. Instead, this report provides the reader with the steps necessary to conduct their own life cycle analysis given their experience with a particular marking material and the information that is provided in this report. For example, in high-volume areas, conventional products are anticipated to last a year. In rural areas, where volumes are low, it is possible to get as many as three years of life out of the same product. The life cycle calculations would have different results given the differences in expected life. The following example shows a cost comparison between epoxy and conventional marking materials.

Step 1:

Given 1 mile of roadway segment that needs to be painted

Current experience with latex/alkyds is a 1-year life span*

Estimated life of epoxy is a minimum of 4 years (expected life found in the matrix in section two of this report)

Step 2:

Take the cost of the material per linear foot (found in the matrix in section two of this report) and multiply it by 5,280 to determine the cost per mile.

Latex: $0.04 per linear foot X 5,280 feet = $211.20

Epoxy: $0.25 per linear foot X 5,280 feet = $1,320

Step 3:

Convert costs.

The costs can be converted to annualized cost by taking the cost per mile and dividing by the life expectancy for the product.

Latex: $211.20/1 = $211.20

Epoxy: $1,320/4 = $330

A more precise method of converting costs brings dollar totals to a present value. Using a 5 percent discount rate (found in engineering tables) the costs for the material are as follows:

Latex: $211.20*3.546 = $749

Epoxy: $1,320

Step 4:

Acknowledge costs/risks for worker/driver exposure to road hazards while marking is occurring. In high volume areas it may be worth the added expense to use a more durable product so that traffic flow is not interrupted and workers and drivers have less exposure to hazardous situations.

*Insert the life of paint based on past experience with conventional materials and typical volumes and sanding/plowing that occur on the given roadway.

APPENDIX

LIFE CYCLE CALCULATIONS